PALMER
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Site Specific Water Budget Report – Cardinal Creek Village Development (R1)

Prepared for

J.F. Sabourin and Associates Inc.

June 24, 2013

PALMER
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CONSULTING
GROUP INC.

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June 24, 2013

Heather Wilson, P.Geo.
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J.F. Sabourin and Associates Inc.
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Dear Ms. Wilson,

Re: Site Specific Water Budget Report – Cardinal Creek Village Development (R1)

Palmer Environmental Consulting Group Inc. is pleased to submit a revised final report describing the results of the Site Specific Water Budget assessment conducted as part of the development application for the proposed Cardinal Creek Village development. This report replaces the Site Specific Water Budget Report dated June 18, 2013. The revision represents minor corrections, clarifications, and edits in response to review comments. These revisions do not change the overall conclusion or recommendations of the report.

Based on the June 2013 Concept Plan for the Cardinal Creek Village (CCV), combined with mitigation measures for maintaining or enhancing infiltration, recharge areas supporting stream baseflow on the CCV site will be maintained post-development. As a result, the development is not predicted to adversely impact groundwater supported stream baseflow or existing water users within and downstream of the study area. This assessment is based on a review of existing reports prepared for the proposed development, field verification conducted in June 2013, and the results of the Water Budget Modeling task completed as part of this study.

If there are any questions or comments on this report, then please contact Mr. Jason Cole at 416-605-5796.

Yours truly,

Palmer Environmental Consulting Group Inc.

J. Cole

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-	Yes	Palmer Environmental Consulting Group

Revision Log

Revision #	Revised By	Date	Issue / Revision Description
1	R. Frizzell	June 17, 2013	QA/QC Review
2	H. Wilson	June 18, 2013	Client Review
3	R.Frizzell	June 20, 2013	Client Review, QA/QC

Signatures

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Revision Log

The following notable revisions to the June 18, 2013 Report are included in this Revision 1 document.

Page, Section in June 18, 2013 Version	Change in June 24, 2013 Revision
Page 1, Section 1.	J.F. Sabourin Inc. report the CCV development is approximately 208 vs. 207 hectares
Page 4, Section 2.2.2	Changes were made to place less emphasis on flow contributions from tile drains and more on general farm drainage features.
Page 7, Section 3.1.2	Stream flow stations were relabeled for clarity.
Page 10, Figure 3	Final Northern Tributary Stream Flow values in the Figure were corrected to match Table 2. The values previously presented were uncalibrated measurements. The North Trib 1 station location was moved on the map to match the correct location of the JFSA stream level monitoring station.
Page 12, Section 3.2.3	It was added that the Worthington Karst Investigation (memo dated June 4, 2013) indicated that "no locations were found where there were abrupt major increases or decreases in flow along any of the creeks". The only groundwater springs documented by Worthington (2013) were along the northern bank of the Southern Tributary.
Page 14 and Page 20, Sections 4.2.1 and 4.3.3	A note was added to clarify that groundwater divides do not necessarily match the surface water divides, particularly in fractured bedrock settings. This assumption is required to compare Water budget values to measured stream flows.
Page 14, Section 4.2.1	Description of how the average surplus for the CCV site is weighted based on the aerial extent of the different soil moisture conditions.
Page 16, Section 4.2.2, Table 6	The Sample Calculation slope factor was changed to 0.3 (flat and average slope) essentially reversing the infiltration and recharge values in this example.
Page 17, Section 4.3.2	Clarification on what Important Recharge Areas represent.
Page 21, Section 4.3.3, Table 7	Edits to the subcatchment areas for the North Trib were made to better match the JFSA stream level monitoring stations. The Water Budget Estimated Contribution to baseflow for North Trib 1 and North Trib 2 areas on Figure 7 was revised to be 1.3 L/s and 2.6 L/sec respectively. The original 4.0 L/s

	estimate reported for Trib 2 was simply the cumulative estimated baseflow from both sub-catchments. This has been corrected to 3.5 L/s (4.0 L/s – 0.5 L/s). Additional description of where baseflow data was derived was added.
Page 22, Section 4.3.3, Figure 7	Figure 7 sub-catchment labels were edited to better clarify the relationship between stream flow stations and water budget results. This resulted in minor variability to catchment areas and flow estimates presented in Table 7 and Table 8. The subcatchment areas that are within the CCV site are now shown to aid the reader.
Page 23, Figure 8	This figure was revised to match the revised baseflow estimates and their position or “level” on the graph.
Page 24, Section 4.3.4.1, Table 8	Contribution to baseflow from CCV Site based on the Water Budget Model was corrected to 2.6 L/s reflecting on the Trib 2 catchment, and not the cumulative baseflow estimation of 4.0 L/s for Trib 1 and Trib 2.
Page 24, Section 4.3.4.2	Additional description of the baseflow analysis for the Northern Tributary was added.
Page 25 and 26, Section 5.2 and 5.3	Additional description of how the potential reduction in baseflow from the CCV site was calculated based on the impervious surface data from the JFSA April 9, 2013 memo.
Page 26, Section 5.2	Reference to the City of Ottawa Storm Sewer Guidelines and basement tile drains was removed. The communication regarding basement tile drains referred to the Northern Tributary.
Page 26, Section 5.3	A clarification was made that flow is primarily driven by surface water drainage (which may include tile drains). Tile drainage would not be considered equivalent to groundwater baseflow.
Page 26, Section 5.3	Reference to the City of Ottawa Storm Sewer Guidelines was removed. It is not clear that the tile drain system would contribute the reported discharge.
Page 27, Section 5.4	Clarification that the emphasis is on the maintenance of the infiltration on the Important Recharge Areas that support the tributary baseflow and natural functions.
Page 27, Section 5.4	Deleted sentence - It is not clear that pre-and post-development infiltration rates will be maintained or have a requirement to be maintained in the

	Important Recharge Areas located north of the Northern Tributary.
Page 28, Section 6.1	Clarification that buried services have been shown to increase infiltration through the placement of granular bedding that has a much higher permeability than the existing marine clay or till. The effectiveness of this measure will depend on site specific soil conditions, native soils surrounding the trenches etc.
Page 28, Section 6.1	Clarification to account for consideration of measures before implementation.
Page 30, Section 7	Clarification that development is not proposed over the vast majority of the IRA's associated with the karstic Bobcaygeon Formation. Development will occur on the IRA's in the north of the site, which are interpreted to recharge the bedrock aquifer flowing directly to the lower reaches of Cardinal Creek and/or the Ottawa River.
Page 23, Figure 8	Correction to North Trib labeling and replaced previous raw stream value with calibrated value (5.9 L/s).
Appendix B3	Removed reference to tile drainage and simplified to describe general farm drainage
Appendix D	Relabeled North Trib stations for clarity and to match report
Appendix E	Reference to Northern Tributary Stations was edited to match relabeling.

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Appendix B. Surficial Geology, Bedrock Geology, and Cross-Section (Paterson, 2013)
Appendix C. Water Balance Precipitation, ET, and Surplus Values
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Appendix E. Summary of Field Investigations

1 Introduction

Palmer Environmental Consulting Group (PECG) was retained by J.F. Sabourin and Associates Inc. (JFSA) to complete a site specific water budget assessment for the proposed Cardinal Creek Village (CCV) development located along the eastern urban boundary of the City of Ottawa (**Figure 1**). The proposed Concept Plan for the CCV development ("the site" or "the development") is presented in **Appendix A**.

The proposed development would be approximately 208 ha in size and include residential, institutional, and mixed use commercial lands.

A site specific water budget is used to determine the relationship between infiltration and runoff on a site, and to ultimately understand groundwater recharge and discharge as it relates to the protection of natural features and groundwater resources. In this case, the site specific water budget could also be considered a feature specific or multi-discipline water budget that focuses on maintaining form and function of existing natural features post-development.

Understanding the relationship between infiltration and runoff also has implications for stormwater management and the site servicing plan. By identifying where the recharge and discharge areas are on the site, engineering design measures can be put in place to avoid or mitigate against potential adverse impacts to these areas.

1.1 Objectives

The objectives of this study for the proposed CCV development are as follows:

- Characterize the groundwater flow regime and understand its relationship in supporting natural features on the site;
- Calculate a Site Specific Water Budget using a GIS-based Model that takes into account the unique features of the CCV site as documented through work completed by others and a site visit;
- Identify the recharge and discharge areas on and surrounding the CCV site;
- Conduct an effects assessment for the potential impacts of the proposed CCV development on the groundwater flow regime, the water budget and groundwater supported natural features; and
- Recommend potential mitigation measures and a monitoring program.

2 Study Procedures

2.1 Background Review

A number of technical reports have been prepared as part of the application for the CCV development. These documents provide an understanding of the site specific conditions that make up the multi-discipline water budget and include:

***Figure* 1 – Site Map: Cardinal Creek Village**

- "Greater Cardinal Creek Subwatershed Study – Existing Conditions Report" August 12, 2009, prepared by AECOM;
- "Existing Conditions Report: Hydrogeology" June 3, 2013, prepared by Paterson Group (surficial geology and bedrock geology maps from this report are included in **Appendix B**);
- "Cardinal Creek Village – Cardinal Creek Tributaries – Fish Habitat and Fish Community – Headwater Assessment" February 2013, prepared by Muncaster Environmental Planning;
- "Draft Evaluation of Karst at Cardinal Creek Village" May 29, 2013, and June 4, 2013 Revised Report, prepared by Worthington Groundwater;
- "Cardinal Creek Village – 2012 Surface Water and Rainfall Monitoring Memorandum" December 14, 2012, prepared by J.F. Sabourin and Associates;
- "Cardinal Creek Village Erosion Threshold Assessment" January 2013, prepared by Parish Geomorphic;
- "Cardinal Creek Village / Water Balance Analysis" May 31, 2013, prepared by J.F. Sabourin and Associates; and
- "Cardinal Creek Village / Post-Development Baseflow Analysis" April 9, 2013, prepared by J.F. Sabourin and Associates.

As part of Source Water Protection Planning, the Rideau Valley Conservation Authority has prepared a comprehensive study of source water in the Mississippi-Rideau Source Protection Area. The following source protection documents were also reviewed and utilized as part of this study:

- "Mississippi-Rideau Source Protection Plan" 2013, prepared by the Rideau Valley Conservation Authority; and
- "Technical Rules: Assessment Report – Clean Water Act" 2006, prepared by the Ontario Ministry of the Environment.

The results from these background reports were relied upon and integrated into this report where appropriate. A site visit conducted during June 2013 was used to confirm the conceptual understanding of groundwater and ecological conditions at the study site as determined from the existing information.

2.2 Existing Conditions

2.2.1 Geology and Hydrogeology

The regional surficial and bedrock geology mapping are presented in **Appendix B** (Paterson, 2013).

The surficial geology is dominated by marine clay, which is comprised of laminated marine silt and clay layers, deposited within the post-glacial Champlain Sea (Chapman and Putnam, 1984). These clay deposits range in thickness from approximately 1 m to greater than 40 m close to the Ottawa River, and cover more than 60% of CCV area based on regional mapping.

Glacial till deposits are also present at surface. Within the study area, the till is described as sandy silt till that tends to be present at the margins of bedrock outcrops and underlies the marine clay.

Minor deposits of coarse-grained glaciomarine sands and gravels are shown on regional mapping to be present along the northeastern boundary of the site. These deposits were formed along the edge of the post-glacial Champlain Sea.

Paleozoic bedrock outcrops from the Middle Ordovician Gull River and Bobcaygeon Formations are present in the study area. The Gull River Formation is described as a fine grained, light grey to brown lithographic to sublithographic limestone with minor siltstone and shaley partings (Williams and Telford, 1986). This unit is horizontally bedded and generally breaks along bedding plane fractures. The Bobcaygeon Formation is described as a crystalline, brown to grey-brown fossiliferous limestone (Williams and Telford, 1986). This unit is highly susceptible to chemical weathering along joints and fractures (i.e., solution enhanced porosity and permeability) and is known to form important karst features to the west of the CCV site.

Groundwater flow in the CCV area is expected to be downward through the low permeability overburden deposits of marine clay and till. Groundwater flow in the more permeable formations, mainly the Bobcaygeon Formation bedrock, is expected to be lateral following the direction and orientation of fractures and joints following the regional groundwater flow. This regional flow is north and north-west towards the lower reaches or Cardinal Creek and the Ottawa River.

2.2.2 Stream Flow

The two dominant surface water features on the CCV site are the Southern Tributary and the Northern Tributary (**Figure 1**). These tributaries drain the majority of the area on the CCV site as well as lands to the east and south (**Figure 7**).

The CCV area, as with much of the Cardinal Creek Subwatershed, is drained by an existing network of ditches/drainage swales and potentially farm tile drains (in some locations) that outlet into the Northern and Southern tributaries.

It has been noted in previous reports that the Northern Tributary regularly goes dry during the summer months and is classified as intermittent. The majority of the Southern Tributary was shown to maintain a permanent flow regime, even through drought years such as 2012, but the eastern portion near Frank Kenny Road commonly goes dry.

Beginning in May 2012, JFSA have collected regular surface water level measurements at 2 locations in the Northern Tributary and at 3 locations in the Southern Tributary *(*shown on **Figure 7**). As part of this study, stream flow estimates were made at or near each of the JFSA monitoring locations in the Southern and Northern tributaries. The results of these measurements are presented in **Appendix D**. A simple field estimation for stream flow was conducted using the US EPA (2012) method of estimating stream flow without a flow meter, which takes into account cross sectional area, flow rate, and a stream bottom roughness factor. This method was modified to account for shorter stream lengths available for collecting flow measurements.

2.2.3 Aquatic Ecology

No Provincially Significant aquatic features (PSW, ESA or ANSI) or Species at Risk have been identified on the CCV site. Fish community sampling conducted by others, identified the presence of tolerant warm-water fish species comprised of creek chub and brook stickleback. These species do not rely on cold groundwater discharge for life functions or spawning habitat. However, maintaining groundwater derived baseflow is important to maintain the existing ecological functions, which includes fish habitat conditions.

2.3 Site Visit

A site visit was conducted by Mr. Jason Cole of PECG and staff from JFSA on June 5, 2013. During this visit, the team walked key post development reaches of the Southern Tributary and the Northern Tributary, visited areas of suspected bedrock outcropping, and observed most of the soil types present within the CCV site.

The objectives of the site visit were as follows:

- Delineate areas of potential groundwater/surface water interactions on the CCV site to understand the relative importance of groundwater supported baseflow in the Southern and the Northern Tributaries;
- Confirm the geology and delineate the occurrence of bedrock at or near surface and the associated karst features on the site;
- Collected stream flow measurements at established monitoring stations within the Southern and Northern Tributaries to compare against 2012 and 2013 stream level data; and
- Identify key areas where infiltration may be maintained through mitigation measures to protect groundwater supported natural features.

2.4 Existing Water Budget Model

In 2009, AECOM Canada Ltd. (AECOM) completed the “Greater Cardinal Creek Subwatershed Study – Existing Conditions Report” (AECOM, 2009) that describes the existing conditions of the Cardinal Creek Subwatershed, where the proposed CCV development is located. As part of this report, a water budget was calculated for the entire Cardinal Creek Subwatershed and modeled using a GIS-based platform (*Figures 4.1 and 4.2* of AECOM, 2009).

This water budget was calculated using a monthly soil-moisture balance approach as described in Thornthwaite and Mather (1957) to determine the average annual evapotranspiration (ET) and surplus (S). Information on precipitation, ET and S, were obtained from Meteorological Services Canada based on data obtained at the Ottawa CDA Station between 1900 and 2005. The mean monthly values are presented in **Appendix C** for a full range of soil moistures.

Subtracting the average annual ET from the average annual precipitation, as determined from the Ottawa CDA data, gives the average annual water surplus. The surplus value is the amount of water available for either infiltration or runoff. The partitioning between infiltration and runoff was determined using a GIS-based model taking into account the physical characteristics of the subwatershed including surficial geology, topographic slope and vegetation cover. Regional mapping was utilized for this GIS analysis.

The results of the AECOM (2009) water budget determined that runoff greatly dominates over infiltration within the Cardinal Creek Subwatershed by a ratio of about 2.5:1. The mean precipitation between the years 1900 and 2005 was 877 mm, and assuming a 300 mm soil moisture value, the mean Potential ET and Surplus were 601 mm and 276 mm, respectively.

The results of this water budget are consistent with the widespread deposits of low permeability marine clay (silty clay to clayey silt) that are present at surface in over 60% of the subwatershed. The average annual infiltration rate over the entire Cardinal Creek Subwatershed was determined to be 82.5 mm. Areas of high infiltration were associated with permeable sands and Paleozoic bedrock at surface and also coincide with terrestrial features such as woodlots and wetlands.

3 Conceptual Model of Groundwater Flow

Understanding groundwater flow at the CCV site is critical for identifying the key recharge and discharge areas, understanding how groundwater flow supports the natural environment, and how and where mitigation measures could be applied to protect natural features and groundwater resources. This section will first describe the results of the field visit and will then present a conceptual model of groundwater flow and how it supports natural environment features on the site.

3.1 Site Visit Results

3.1.1 Southern Tributary

The following details the results of the Southern Tributary field investigations as described in the photographs and data presented on **Figure 2**. A detailed description of each photograph and location is provided in **Appendix E1**.

The Southern Tributary was walked from its eastern extent at Frank Kenny Road to the western edge of the CCV site boundary. Stream flow upstream of the site at South Trib 1 (**Figure 2**) was measured to be 5.3 L/s (**Table 1**). Moving downstream, an area of groundwater discharge from springs was observed (photograph 2). These springs were contributing a noticeable amount of flow to the watercourse. The water temperature of the springs was approximately 7°C, consistent with a deeper groundwater source. More springs were observed further downstream, adding to stream flow (photograph 3). Stream flow was measured at South Trib 2 station to be 20.8 L/s (**Table 1**). Approximately 3.4 L/s of this flow was derived from surface water inputs from some small tributaries, surface drains and/or tile drains, and from the northern branch. The remaining flow increase of 12.1 L/s between South Trib 1 and South Trib 2 is interpreted to have come from groundwater discharge.

Table 1 – Southern Tributary Field Data Summary

Stream Flow Station	Measured Flow Rate	Water Temperature
South Trib 1	5.3 L/s	12°C
South Trib 2	20.8 L/s	13°C
South Trib 3	27.4 L/s	10°C
South Trib 4	13.8 L/s	12°C

Note: Air temperature on June 5, 2013 was between 12 and 17°C.

Downstream of South Trib 2, sidebank seepage was frequently noted (photographs 4 and 5). This seepage was occurring from the interface between the weathered marine clay and the unweathered marine clay. The stream bed sediments over this reach were dominated by hard marine clay (photograph 6), which would generally prevent groundwater discharge except at discrete locations.

Stream flow at South Trib 3 was measured to be 27.4 L/s (**Table 1**), with approximately 2.6 L/s of this flow derived from Mid Branch 2. This is represents an increase of 4.0 L/s from groundwater discharge and seepage over the upstream South Trib 2 station.

Moving downstream, the gradient of the Southern Tributary flattens out and it enters a backwatered, swamp area containing thick deposits of coarse sand and rounded gravel (photographs 7 and 8). The stream flow measured at South Trib 4 Station was 13.8 L/s, which is a decrease of 13.6 L/s from South Trib 3 or about 50% of flow. Much of the stream flow is interpreted to be lost to subsurface flow in the thick sediments within this area. Beyond this point, the tributary loses its defined channel.

3.1.2 Northern Tributary

The following details the results of the Northern Tributary field investigations as described in the photographs and data presented on **Figure 3**. A detailed description of each photograph and location is provided in **Appendix E2**.

Upstream of the CCV site at Ted Kelly Road (North Trib 1), minor flow was observed to be entering the site (photograph 18). The flow was insufficient to be measured but was estimated at about 1 L/s (**Table 2**). Stream flow exiting the culvert at La Porte Nursery at North Trib 2 station was measured to be 5.9 L/s, a gain of approximately 4.9 L/s. Moving downstream, the Northern Tributary flows over exposed Gull River Formation bedrock (photograph 13), which was observed to be horizontally bedded and have limited solution enhanced porosity. Groundwater seepage from the thin overburden was noted along the banks of the tributary.

Table 2 – Northern Tributary Field Data Summary

Stream Flow Station	Measured Flow Rate
North Trib 1	~1 L/s
North Trib 2	5.9 L/s
North Trib 3	8.7 L/s
North Trib 4	5.4 L/s

Note: no temperature measurements were collected in the Northern Tributary

At the base of the bedrock outcrop, the stream flow was measured to be 8.7 L/s at North Trib 3 (**Table 2**). This is a 2.8 L/s increase over this reach and is likely attributed to groundwater discharge from the Gull River Formation.

Similarly to the Southern Tributary, downstream of North Trib 3, the Northern Tributary loses its steep gradient and defined channel as it enters into a backwater, swamp area (photograph 14). The watercourse regains its defined channel again and flows on hard marine clay towards Cardinal Creek. Flow was measured at the North Trib 4 station, located at a steep cut-slope, to be 5.4 L/s, which is a decrease of 3.3 L/s from the previous flow measurement (photograph 15). Much of the stream flow is interpreted to be lost to subsurface flow in the backwatered, swamp area. Fish were observed in the tributary, downstream of the backwatered, swamp area.

3.2 Conceptual Model of Groundwater Flow at the CCV Site

Figure B3 in **Appendix B** presents the conceptual model of groundwater flow at the CCV site. This figure is adapted from the Hydrogeological Cross Section A-A' completed by Paterson (2013), with the groundwater flow lines added as part of this study. The thickness of the flow lines is meant to convey the relative significance of each individual groundwater flow path. It is important to have an established conceptual model of groundwater flow as it relates to infiltration, runoff, and support of natural environment features, to interpret the result of the water budget model.

3.2.1 Groundwater Flow Regime

Groundwater flow at the CCV site is complicated by the presence of low permeability marine clay deposits present at surface that overlie karstic carbonate bedrock. As a result of these unique conditions, solution enhanced secondary porosity features (i.e., epikarst, joints, fractures, etc.) are believed to largely control infiltration and groundwater flow at the site.

The direction of groundwater flow is control by surface topography and the orientation of bedrock fractures and joints. Groundwater flow is downward through the low permeability overburden deposits of marine clay and till. Shallow groundwater flow paths subtly reflect the topographic contours on the site and locally the groundwater flow paths will bend towards incised river valleys and areas of major changes in elevation (**Figure B3**). Interflow of groundwater is expected to occur where shallow low permeability deposits of unsaturated marine clay are present.

Deep groundwater flow in the bedrock follows the orientation of the regional joint sets and fractures (solution enhanced by karst processes), dominated by flow in an approximately northeast-southwest direction, and ultimately discharging into the lower reaches of Cardinal Creek or the Ottawa River (**Figure B3**).

Topographic highs where exposed bedrock is present at surface are significant recharge areas for the CCV site. Groundwater recharge through the marine clays is limited by its low permeability; however, the

Figure 2 – Southern Tributary: Results of June 5, 2013 Site Visit

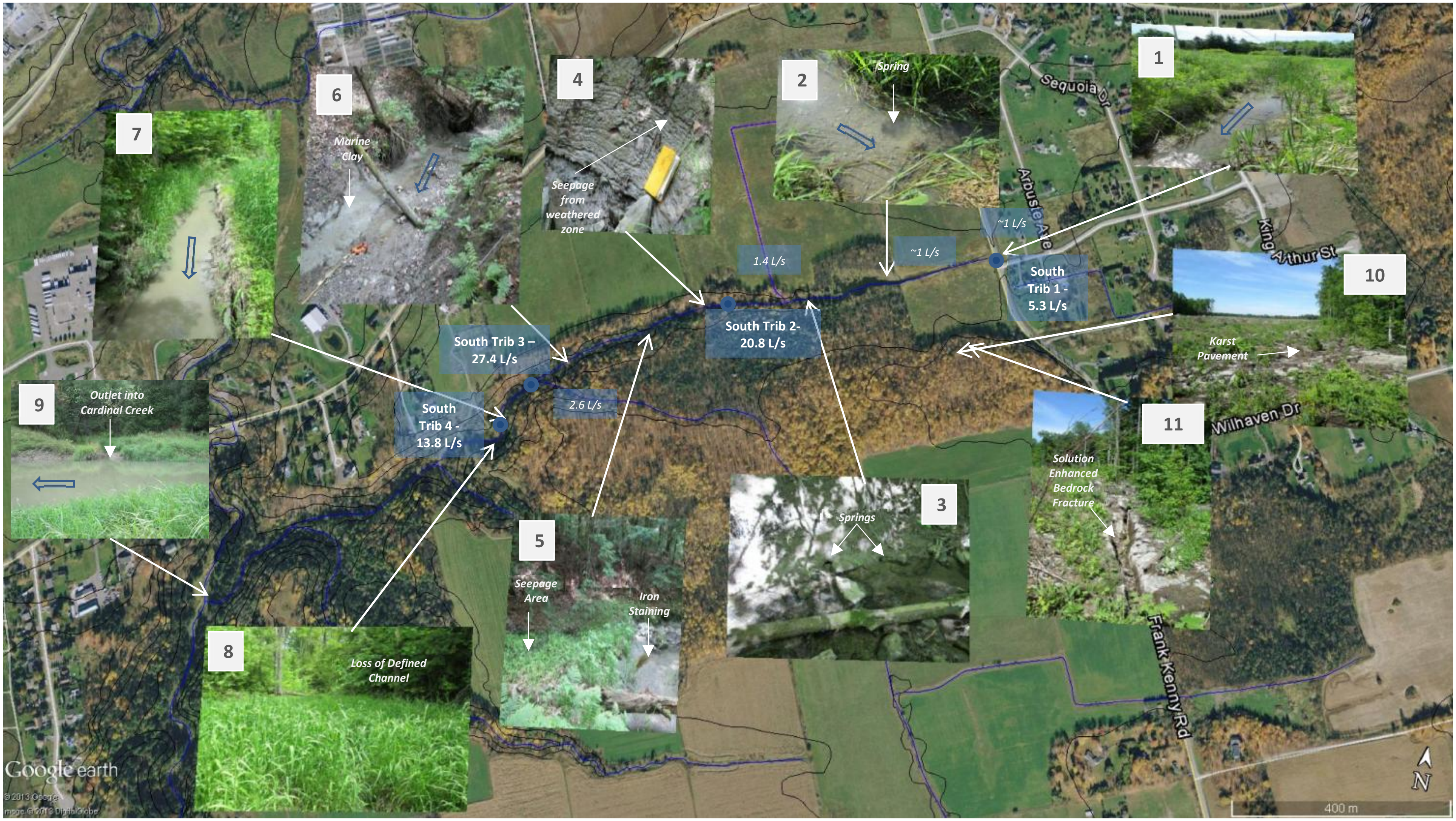
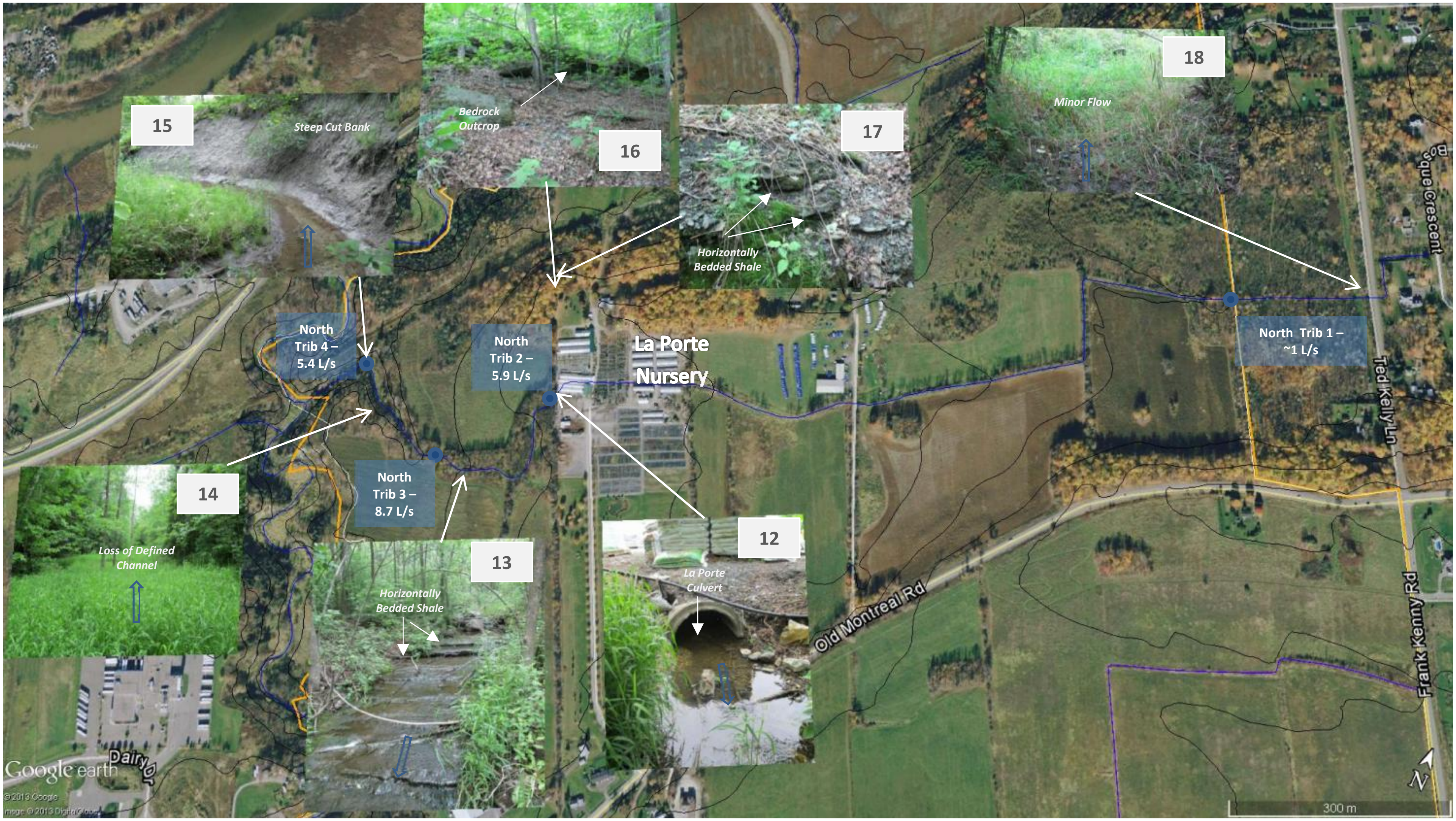


Figure 3 – Northern Tributary: Results of June 5, 2013 Site Visit



upper ~1 m of the marine clay deposits does have a higher permeability due to the presence of secondary porosity features such as cracks and rootlets. Groundwater discharge occurs where the groundwater table intersects the ground surface. This generally occurs at topographic lows or in places where strong upward hydraulic gradients occur.

The two primary aquifers on the site are the Gull River Formation and the Bobcaygeon Formation bedrock. The Gull River Formation bedrock does not show obvious signs of karstic porosity and groundwater flow is likely controlled by thin bedding plane partings and fractures. The Bobcaygeon Formation bedrock shows obvious signs of solution enhanced porosity, including both micro and macro karst features. Groundwater flow in this unit is controlled by the degree of solution enhancement and the regional fracture/joint orientations.

3.2.2 Groundwater Contribution to the Southern Tributary

Stream flow in the Southern Tributary is predominantly derived from surface water runoff and inputs from the farm drainage (including tile drains). The upper reaches, located on the eastern portion of the CCV site and to the east of Frank Kenny Road, are considered to be intermittent in nature and will generally go dry during the summer low flow period. Both the middle and lower reaches of the Southern Tributary are considered to be permanently flowing streams supported by groundwater baseflow.

Based on field observations and the results of the technical reports prepared for the CCV site, it is believed that baseflow in the middle and lower reaches is primarily derived from groundwater discharge from karst springs, which are fed by the exposed Bobcaygeon Formation bedrock located south of the tributary (**Figures B1** and **B3**). Rainfall rapidly infiltrates through these solution enhanced northeast-southwest trending bedrock fractures and joints and discharges into the Southern Tributary as baseflow. Bedrock controlled springs occur only at discrete locations where the overburden is believed to be thin or absent. Local seepage from the upper weathered overburden contributes a small portion to stream flow following precipitation events and during wet seasons. Since these seeps are not connected to a permanent groundwater source, they do not constitute a sustained baseflow source.

Although some of the infiltration through the fractured Bobcaygeon bedrock discharges into the Southern Tributary, some of this infiltration also becomes deep groundwater recharge. This deep groundwater ultimately discharges into the lower reaches of Cardinal Creek and the Ottawa River.

3.2.3 Groundwater Contribution to the Northern Tributary

Similar to flow in the Southern Tributary, stream flow in the Northern Tributary is predominantly derived from surface water runoff and inputs from the drainage network. The likelihood of groundwater discharge into the middle and upper reaches, located east of the La Porte Nursery and east of Ted Kelly Road, appears to be limited. This interpretation is based on the presence of a poorly incised stream channel, thicker deposits of marine clay and till below the tributary, and the presence of Gull River Formation bedrock that does not show widespread solution enhancement. Although watercress, which is an indicator of groundwater discharge, was observed by Muncaster (2013), the amount of stream flow derived from this discharge appears to be insufficient to support sustained flow in the tributary. Results of the 2012 and 2013 stream flow monitoring and field observations show that the middle and upper reaches of the Northern Tributary are intermittent in nature and will generally go dry in the summer low flow period.

West of the La Porte Nursery, the Northern Tributary encounters shallow bedrock and a steep gradient going down a bedrock ridge. Although the fine grained Gull River Formation bedrock is interpreted to contribute less to groundwater recharge and discharge than the solution enhanced Bobcaygeon Formation, this unit still provides an important source of groundwater discharge to the Northern Tributary in the area west of the La Porte Nursery.

It should be noted that an investigation of karst flow and the potential groundwater contribution to streams was undertaken by Worthington Groundwater (June 4, 2013). The resulting memo indicated “no locations were found where there were abrupt major increases or decreases in flow along any of the creeks”. The only groundwater springs documented by Worthington (2013) were along the northern bank of the Southern Tributary, similar to that described above.

4 Site Specific Water Budget

4.1 Site Specific Geology

A key step in understanding the site specific water budget is to confirm the site specific geological conditions. It is common that local geological conditions differ slightly from regional mapping, as the historic regional mapping was typically produced using air photo interpretation.

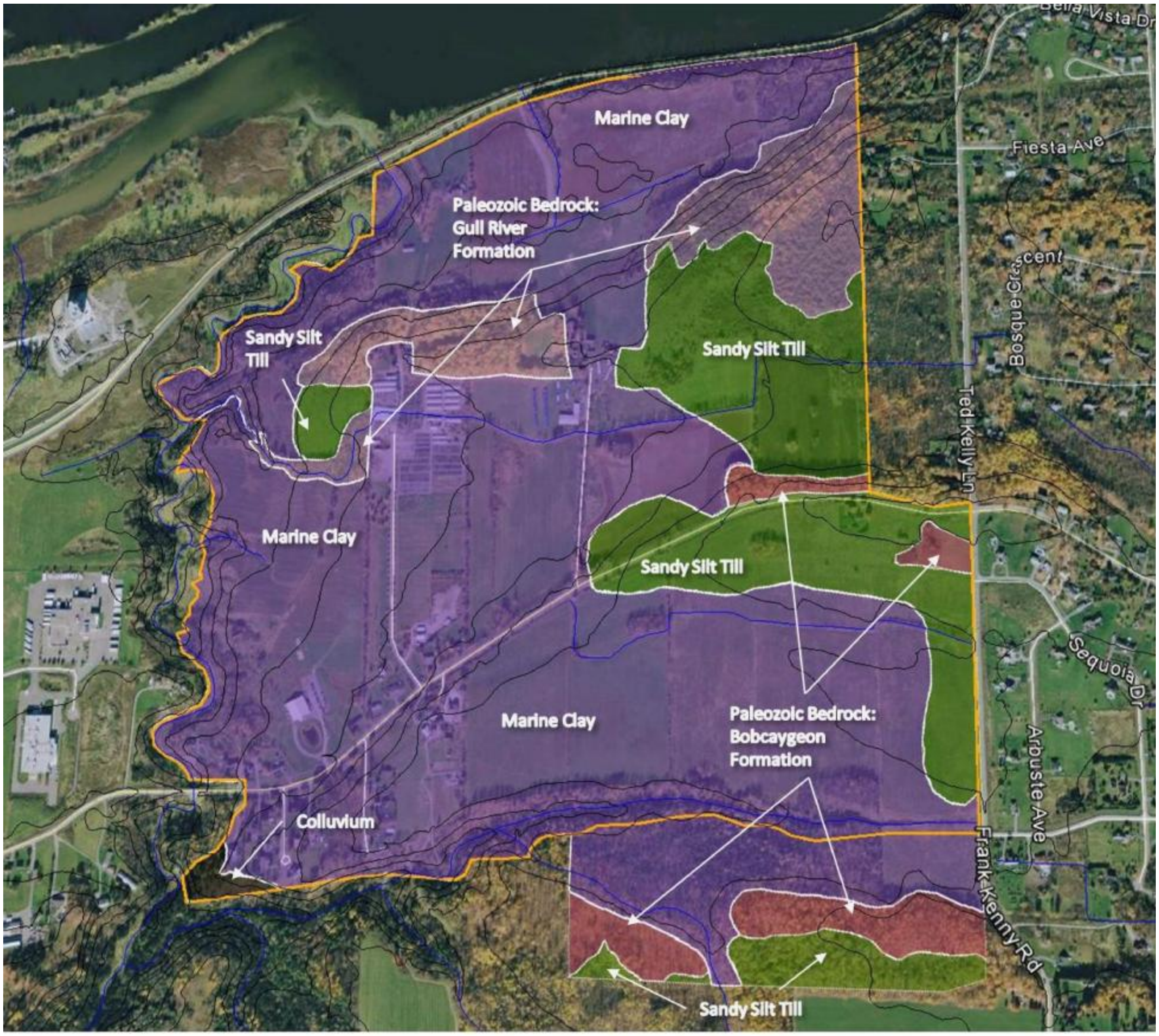
As part of the Hydrogeology Study undertaken by Paterson Group (2013), over 100 boreholes were drilled and 58 test pits were dug to document the site specific geological conditions. During the field investigation conducted on June 5, 2013, most of the geological units shown on regional mapping were visited and the surficial geology documented. Of particular interest were the aerial extent and classification of exposed and thinly covered bedrock, and the presence of glaciomarine sand and gravel.

Figure 4 presents the results of the interpreted site specific geology for the CCV site. The site specific geology was interpreted from borehole and test pit logs (Paterson, 2013), where the first stratigraphic unit encountered was at least 1 m thick, from site specific observations made by PECG, topographic conditions, and from terrain mapping using orthophotography.

A number of site specific changes to the regional surficial geology mapping (shown on **Figure B1**) were made (in **Figure 4**) to better reflect the surficial geology conditions on the CCV site; these include:

- The Paleozoic bedrock near the Northern Tributary was classified as Gull River Formation and moved northwards to coincide with the bedrock outcrop present south of the abandoned railway crossing and north of the Northern Tributary;

Figure 4 – Site Specific Surficial Geology for the CCV Site



- Outcropping of the Gull River Formation was shown on the lower reaches of the Northern Tributary west of La Porte Nursery;
- The area identified as glaciomarine sand and gravel was changed to till based on the large amount of borehole and test pit evidence indicating that no course-textured glaciomarine deposits were present on-site;
- Bedrock outcrops near the intersection of Old Montreal Road and Frank Kenny Road were added based on field observations and test pit data that showed overburden thickness to <1 m.
- The area of till at surface was expanded both north and south of Old Montreal Road near Frank Kenny based on borehole and test pit data; and
- The extent of shallow or exposed bedrock of the Bobcaygeon Formation located south of the Southern Tributary was reduced in size based on borehole and test pit data and field observations.

It is important to note that surficial geology was only re-interpreted for the area *within the CCV site boundary*. Insufficient information was available to re-interpret the surficial geology conditions outside of the study area with a high level of accuracy. The regional surficial geology mapping shown on **Figure B1** was relied upon for analysis outside of the CCV boundary.

4.2 Site Specific Water Budget

4.2.1 Water Surplus

The water surplus describes the difference between precipitation and evapotranspiration (ET) to estimate the amount of water or *surplus* that is available to contribute to infiltration and runoff. The precipitation, ET and surplus data used for the site specific analyses of the CCV site were the same as were used in the AECOM (2009) water budget for the Greater Cardinal Creek Subwatershed – Existing Conditions Study.

In order to assume that changes in surface water storage and groundwater storage are negligible and can be removed from the final water budget calculation, the water budget must be calculated over the full drainage area or watershed of all surface water bodies present. Because the CCV site boundaries do not coincide with the watershed boundaries of the Northern and Southern tributaries, the study area was expanded as shown in **Figure 5, 6 and 7,** to include both the CCV site and the Northern and Southern tributary drainage areas. It is recognized that groundwater flow boundaries do not necessarily coincide with surface water flow boundaries, but it was necessary to make this assumption for the purposes of this analysis.

The water budget was calculated over the expanded study area using a monthly soil-moisture balance approach as described in Thornthwaite and Mather (1957) to determine the average annual ET and surplus. Information on precipitation, ET and surplus, were obtained from Meteorological Services Canada based on data obtained at the Ottawa CDA Station between 1900 and 2005. The mean monthly values are presented in **Appendix C** for a full range of soil moistures.

Using site specific knowledge of soil conditions, the surplus values were differentiated for each range of soil moisture holding capacity based on geology and vegetation cover. **Table 3** presents the surplus values that were used for each soil type present. Each soil type was assigned a unique value of surplus in the site specific water budget model for the CCV site. The average annual surplus for the CCV site was calculated to be 292 mm and is based on surplus values weighted to reflect the aerial extent of each soil type/ soil moisture condition.

Table 3 – Site Specific Water Surplus Values

Soil Type		**Soil Moisture (mm)**		**Surplus (mm/yr)**	
OGS Number	Description	Wooded Area	Open Field/ Cultivated	Wooded Area	Open Field/ Cultivated
10a	**Marine Clay**	300	200	276	290
3a	**Gull River Bedrock**	100	50	336	376
3b	**Bobcaygeon Bedrock**	100	50	336	376
18	**Colluvium**	100	50	336	376
5b	**Till**	300	200	276	290
11b	**Glaciomarine Sand and Gravel**	200	100	290	336
20	**Organics**	400	300	270	276

Note: The Water Holding Capacity of the soils were determined using Table 3.1, MOE SWM Planning and Design Manual, March 2003.

4.2.2 Infiltration Factors

The partitioning of the water surplus between runoff and infiltration depends on soil type, topography and vegetation cover. Water will infiltrate more easily through sands compared to clays, on flat slopes compared to steep slopes, and through naturally vegetated soils compared to agricultural crops or urban areas. The method developed by Bernard (1932) and described by the MOEE (1995) was programed into the Water Budget Model that was used to spatially determine the infiltration factors across the property.

The infiltration factors are described in the MOEE manual, and are reproduced here for reference (**Table 4**). The infiltration factor is calculated by summing the individual sub-factors at the site. The water surplus is then multiplied by the total infiltration factor to determine the partitioning between the amount of runoff and the amount of infiltration that occurs annually. This is done in the Water Budget Model to represent the special extent and variability of infiltration.

Table 4 – MOEE (1995) Infiltration Factors

Description of Area/Development Site	Value of Infiltration Factor
TOPOGRAPHY	
• Flat and average slope not exceeding 0.6 m per km	0.30
• Rolling land, average slope of 2.8 m to 3.8 m per km	0.20
• Hilly land, average slope of 28 m to 47 m per km	0.10
SOIL	
• Tight impervious clay	0.10
• Medium combinations of clay and loam	0.20
• Open sandy loam	0.40
COVER	
• Open Fields/Cultivated Lands	0.10
• Woodlands	0.20

Note: Reproduced from MOEE (1995), Technical Guidelines for the Preparation of Hydrogeological Studies for Land Development Applications

As shown on **Figure 4**, the surficial soils on the CCV site are comprised mainly of marine clay and till, with lesser amounts of exposed bedrock and colluvium. The area outside of the CCV site also contains glaciomarine sand and gravel, and organics (**Figure B2**).

Table 5 presents the interpreted soil infiltration factors used for the site specific water budget. The selection of these values is based on the MOEE (1995) values shown on **Table 4** with site specific interpretations of the relative infiltration capacity of the CCV site soils made to reflect site conditions. All other infiltration factors (i.e., vegetation and topography) used in the model were unchanged from the MOEE (1995) values. The runoff is the total amount of surplus remaining after taking into account infiltration or (1) – (infiltration factor) = (runoff factor).

Table 5 – Site Specific Infiltration Factors

OGS Number	Description	Infiltration factor
10a	**Marine Clay**	0.1
3a	**Gull River Bedrock**	0.2
3b	**Bobcaygeon Bedrock**	0.4
18	**Colluvium**	0.4
5b	**Till**	0.2
11b	**Glaciomarine Sand and Gravel**	0.4
20	**Organics**	0.4

To aid the reader, **Table 6** presents a sample calculation from the Water Budget Model to show how the different infiltration factors and water surpluses are partitioned or added together to obtain an estimate of recharge and runoff using the Water Budget Model.

Table 6 – Sample Calculation of Infiltration/ Runoff Partitioning from Water Budget Model

Factor	Condition	Value
Topography	Flat Slope	0.3
Soils	Till	0.2
Vegetation	Cultivated Field	0.1
	Infiltration Factor	0.6
	Runoff Factor	0.4
Soil Moisture	Till below Cultivated Field	200 mm
	Surplus	290 mm
	Infiltration	174 mm
	Runoff	116 mm

4.3 Cardinal Creek Village Water Budget

The Site Specific Water Budget Infiltration and Runoff results are presented on **Figures 5** and **6**. The infiltration was calculated based on the surplus values and infiltration factors as described in the previous section.

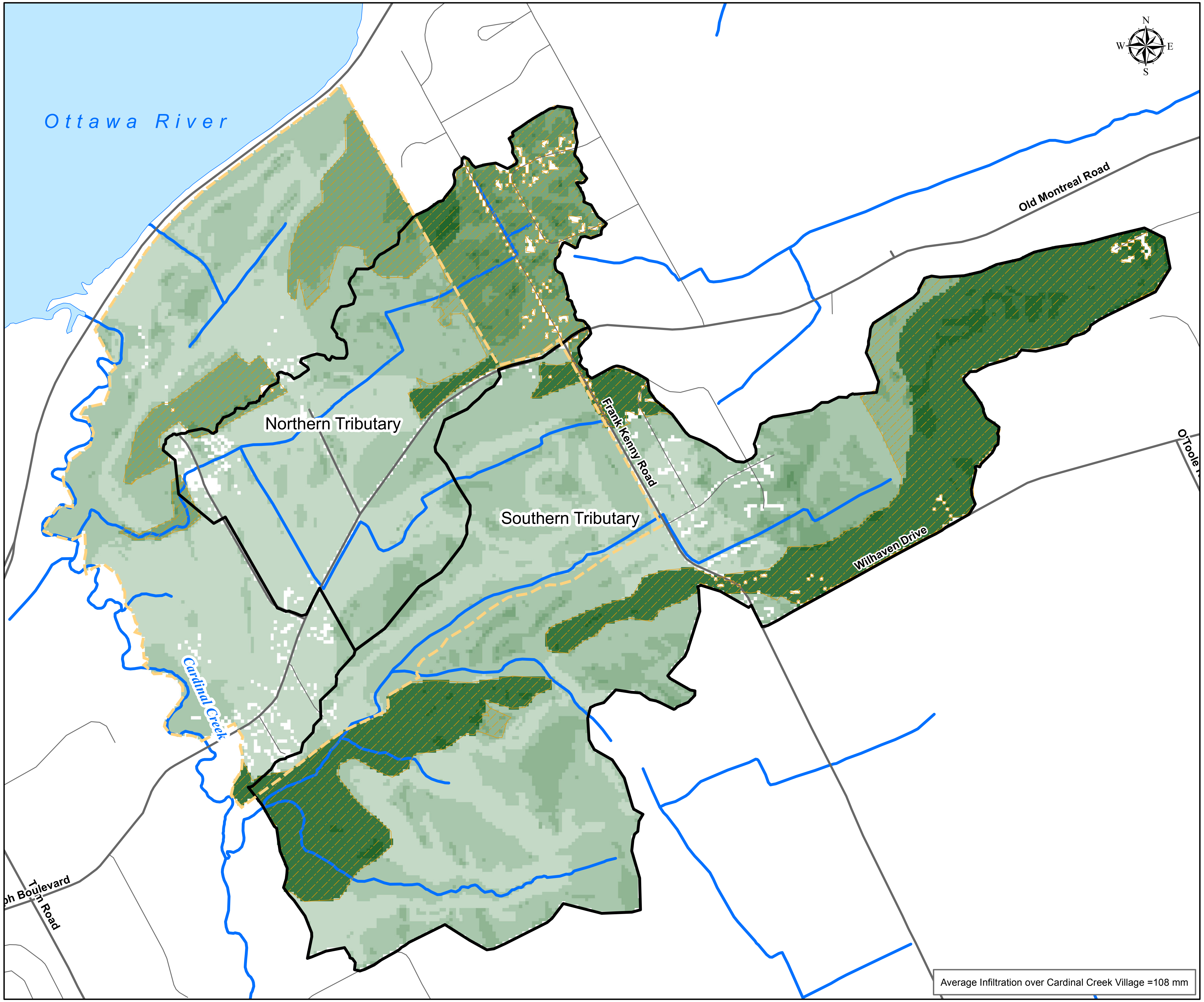
As shown on **Figure 5 and 6** respectively, the average annual infiltration over the CCV site is 108 mm and the average annual runoff is 184 mm. This value for infiltration is higher than the value calculated by AECOM (2009) for the entire Cardinal Creek Subwatershed, which was 82.5 mm. However, the original AECOM water budget model was updated for the Greater Cardinal Creek Subwatershed Plan Report (AECOM, 2013 *in progress*), and it is our understanding that the results will show an average infiltration for the subwatershed that is closer to the average infiltration calculated herein for the CCV site.

Some additional changes to the Site Specific Water Budget were made that differ from both the original AECOM model (AECOM, 2009) and the updated model (AECOM, 2013 *in progress*), and include: i) the expanded extent of surficial till deposits (more permeable than the marine clays), ii) assigning a higher infiltration value to the Bobcaygeon Formation bedrock to account for solution enhanced karstic porosity, and iii) differentiating surplus values based on soil specific soil moisture holding capacities.

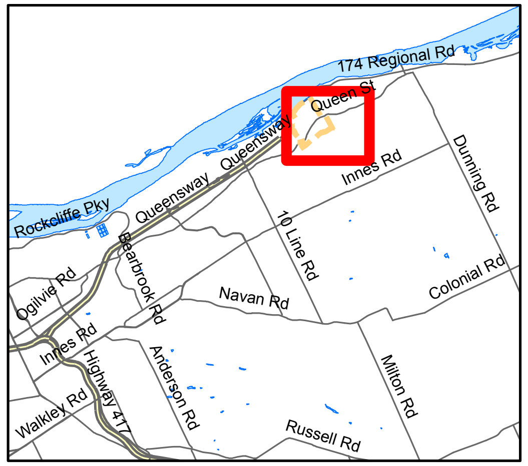
4.3.1 Discussion of Water Budget Results

Areas underlain by marine clay, which are known to have low infiltration capacities, are generally within the 50 – 100 mm range for annual infiltration (**Figure 5**). Based on experience, this type of marine clay would more commonly be on the lower end of that range. For the purposes of calculations for the CCV development, an average value of 75 mm was selected for these soils.

Areas underlain by Paleozoic bedrock of the Bobcaygeon Formation have the highest infiltration capacity of all soils within the CCV area at more than 250 mm. This is a reflection of the micro and macro karst



Average Infiltration over Cardinal Creek Village =108 mm



Legend

- ▭ Cardinal Creek Village Area
- ▭ North and South Tributary Monitor Drainge Areas
- ▨ Important Recharge Areas (CCV Site and Tributary Drainage Areas)
- ― Stream Network

Recharge (mm)

- ▭ < 25
- 🟩 25 - 50
- 🟩 50 - 100
- 🟩 100 - 125
- 🟩 125 - 150
- 🟩 150 - 175
- 🟩 175 - 200
- 🟩 200 - 225
- 🟩 225 - 250
- 🟩 > 250

Note:
- SGRA (study area) were determined bsaed on the average infiltration over the CCV study area boundary.
- SGRA (subwatershed) were determined bsaed on the average infiltration over the entire Cardinal Creek subwatershed.
- AECOM water balance model was used in the analysis.

0 0.25 0.5
Km
1:12,000

Infiltration

Drawn By: O. Chung
Checked By: J. Cole
Date: 4 June 2013
Projection: North American Datum 1983 UTM Zone 17

1:50,000 Topographic Spatial Data: Canvec; courtesy of Her Majesty the Queen in Right of Canada, Department of Natural Resources. All Rights Reserved.

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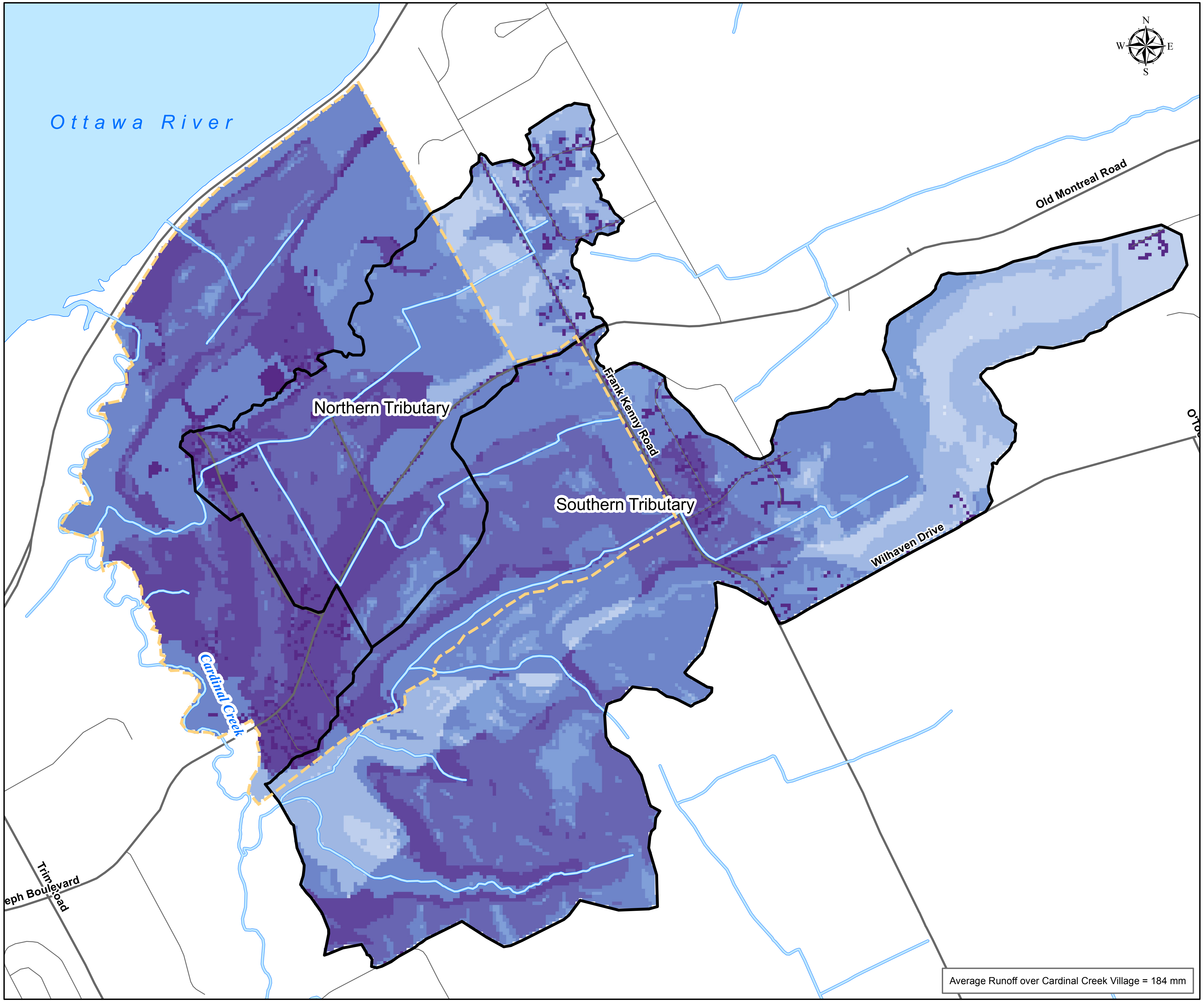
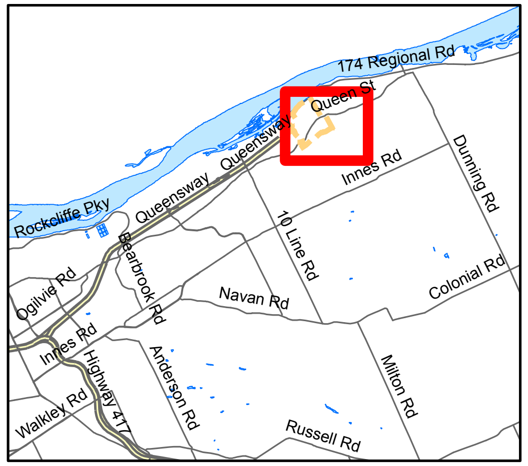
Figure 5



Average Runoff over Cardinal Creek Village = 184 mm



Legend

Cardinal Creek Village Area
North and South Tributary Monitor Drainge Areas
Stream Network

Runoff (mm)

- < 25
- 25 - 50
- 50 - 100
- 100 - 125
- 125 - 150
- 150 - 175
- 175 - 200
- 200 - 225
- 225 - 250
- > 250

Note:
- AECOM water balance model was used in the analysis.

0 0.25 0.5
Km
1:12,000

Surface Runoff

Drawn By: O. Chung
Checked By: J. Cole
Date: 4 June 2013
Projection: North American Datum 1983 UTM Zone 17

1:50,000 Topographic Spatial Data: Canvec; courtesy of Her Majesty the Queen in Right of Canada, Department of Natural Resources. All Rights Reserved.

This document is not an official land survey and the spatial data presented is subject to change without any notice.

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Figure 6

features identified in this unit. Areas underlain by Paleozoic bedrock of the Gull River Formation have a much lower infiltration capacity, at about 150 – 175 mm, which is a reflection of the finer grained rock matrix, and limited reported karst development.

4.3.2 Important Recharge Areas

The Greater Cardinal Creek Subwatershed Plan (AECOM, 2013 *in progress*), identifies areas called Sensitive Recharge Areas (SRAs). These areas were delineated based on the same methodology used in the Mississippi-Rideau Source Protection Plan (RVCA, 2013) to determine Significant Groundwater Recharge Areas (SGRA), but were tailored to the recharge values of the Cardinal Creek Subwatershed rather than the entire Mississippi-Rideau Source Protection Area.

It was determined that an infiltration value of 129 mm or greater constitutes a SRA for the Cardinal Creek Subwatershed (AECOM, 2013 *in progress*). It is recommended in the AECOM report that in these areas, the pre-development infiltration function must be maintained post-development.

Based on the Site Specific Water Budget Model results, areas within the proposed CCV development where the infiltration was 129 mm or greater, were identified as Important Recharge Areas (IRA's) (**Figure 5**). These are the areas that have the highest infiltration and groundwater recharge rates within the CCV area, and in some cases, support deep groundwater flow or groundwater discharge.

4.3.3 Comparison to Stream Baseflow

In order to validate the results of the water budget model, the calculated values must be compared against field derived stream baseflow values, which represent the amount of water leaving the watershed.

If it is assumed for the purpose of the water budget analysis that the drainage areas for the Northern and Southern Tributaries are equal to the groundwater flow divides, then the annual infiltration rate (in mm/yr or m/yr) can by multiplied by the drainage area (in m^2) to estimate the total amount of groundwater flowing out of the watershed through stream baseflow (in m^3/yr or L/s). As noted, groundwater divides do not necessarily coincide to surface water drainage areas, particularly in fractured rock settings.

Figure 7 shows the location of each JFSA surface water monitoring station, the surface water catchment area for each station, and the location where the coinciding stream flow estimates were made as part of the June 5, 2013 PECG site visit. **Figure 8** presents the results of the JFSA stream depth measurements collected between May 2012 and June 2013, and the stream flow estimates collected by PECG on June 5, 2013.

Insufficient stream flow data was available at each JFSA monitoring station to produce a stage discharge curve to convert stream depth (stage) into flow (discharge). Only a relative comparison between depth and flow is made on **Figure 8**. All that can be confirmed from this graph is that discharge at stream depths below the flow line are generally less than the flow measured on June 5, 2013, and stream depths above the flow line are generally greater than the flow measured on June 5, 2013 (note that the relationship between depth and stream flow changes as the channel cross-section changes over time).

Although exact baseflow values cannot be derived from the plot shown in **Figure 8**, it does however provide insights into the relative importance of baseflow, and what a reasonable estimate of baseflow values might be for both the Northern and Southern tributaries to compare against the water budget results.

Table 7 presents the average infiltration over each of the catchment areas, the estimated baseflow derived from the Water Budget infiltration results, and the estimated baseflow data for both the Northern and Southern tributaries based on field data (**Tables 1** and **2**; **Figure 8**) and observations. Additional surface water monitoring data is required to confirm the baseflow values for both tributaries, but the values presented herein are believed to be reasonable estimates based on the available data.

The cumulative baseflow based on the Water Budget infiltration matches well with the expected baseflow value observed in the field and presented on **Table 7**. This suggests that the methods for determining the water surplus and infiltration factors were reasonable for the study area.

Table 7 – Stream Baseflow Summary and Comparison

Station	Subcatchment Areas (Figure 7) (m^2)	Average Infiltration (mm)	Water Budget Estimated Contribution to Baseflow* (L/s)	Field Data Estimated Contribution to Baseflow* (L/s)	Baseflow Difference (L/s)
South Trib 1	796,691	177	4.5	1.0	3.5
South Trib 2	500,231	156	2.5	6.0	-3.5
South Trib 3	155,051	153	0.8	2.0	-1.2
North Trib 1	248,340	168	1.3	0.5	0.8
North Trib 2	646,826	127	2.6	**3.5	-0.9

*Note: * - the contribution to baseflow from each subcatchment area was derived from subtracting the total subcatchment baseflow value from the total upstream subcatchment baseflow value.*
*** - Estimated from June 5, 2013 stream flow measurement, and baseflow separation from continuous flow logger data May to June 2013 (JFSA Pre-development Baseflow Analysis memo).*

While the potential cumulative baseflow values from the infiltration estimates match the estimated cumulative baseflow values from stream level data relatively well, the contribution from each drainage area do not match well. This may simply result from inherent uncertainty in the water budget estimates, uncertainty in estimated stream baseflow and/or differences between groundwater divides and the surface water catchments. Collection of additional and higher quality baseflow data is recommended as part of this report (described in Section 6.2).

Based on the values of the Difference Between Water Budget Estimated Baseflow and Field Data Estimated Baseflow (**Table 7**), it can be seen that relative contribution from some reaches has been under or over estimated. In cases were potential contribution to baseflow has been over estimated, the differences may be attributed to the loss of groundwater to deeper regional groundwater recharge that does not discharge within the subwatershed (i.e., South Trib 1), or may result from a simple overestimation of the infiltration capacity of the soils within the drainage area (i.e., North Trib 1). Where the contribution to baseflow has been significantly under estimated by the water budget model (i.e., South Trib 2 and 3), this may be attributed to bedrock derived groundwater discharge through karst springs that are adding to stream flow over this reach (South Trib 2), or as described above, may be related to uncertainty in baseflow estimates and /or infiltration values. Where the contribution to baseflow from the Water Budget more closely matches the field estimated baseflow (i.e., North Trib 2), then it can generally be concluded that baseflow is likely derived from within the catchment and that no significant external source (i.e., groundwater discharge) are contributing to stream flow.

Figure 7 – Northern and Southern Tributary Subcatchment Areas and Stream Monitoring Stations

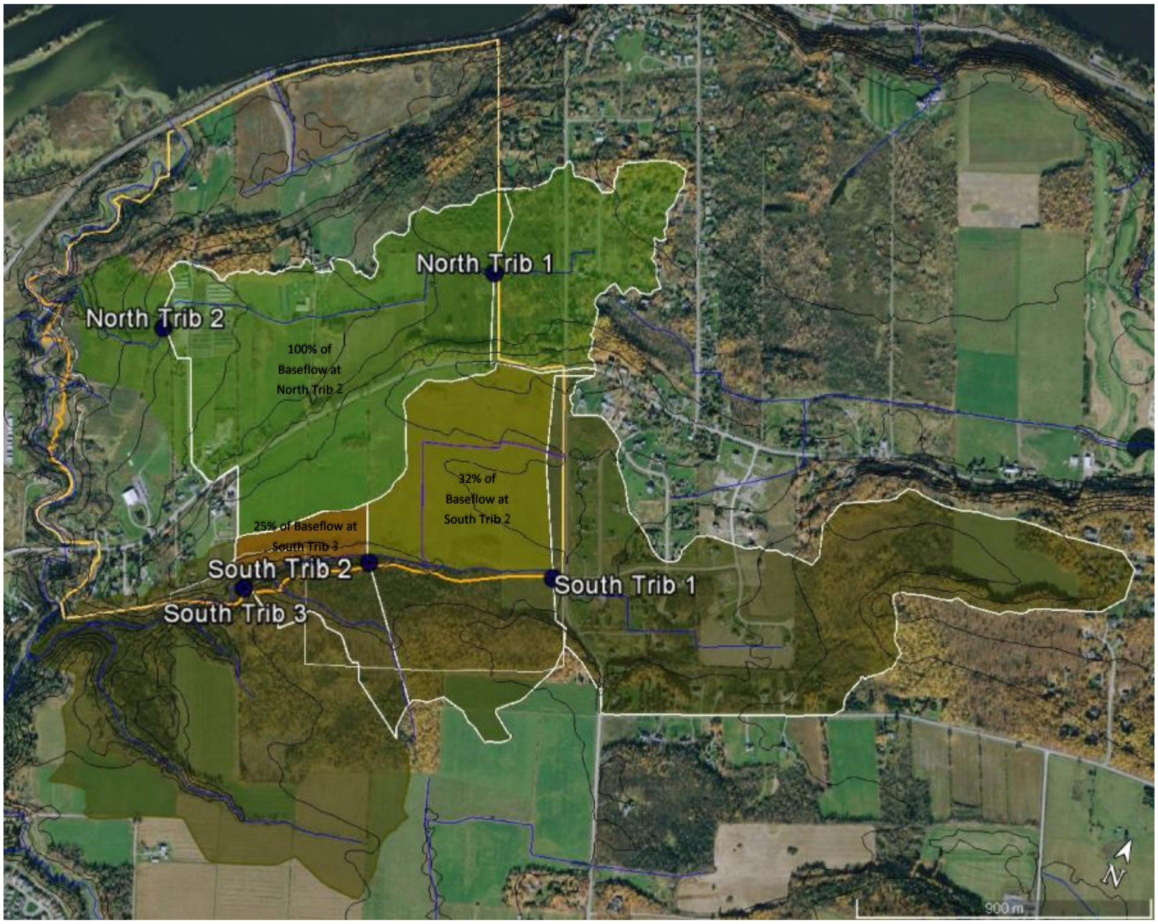
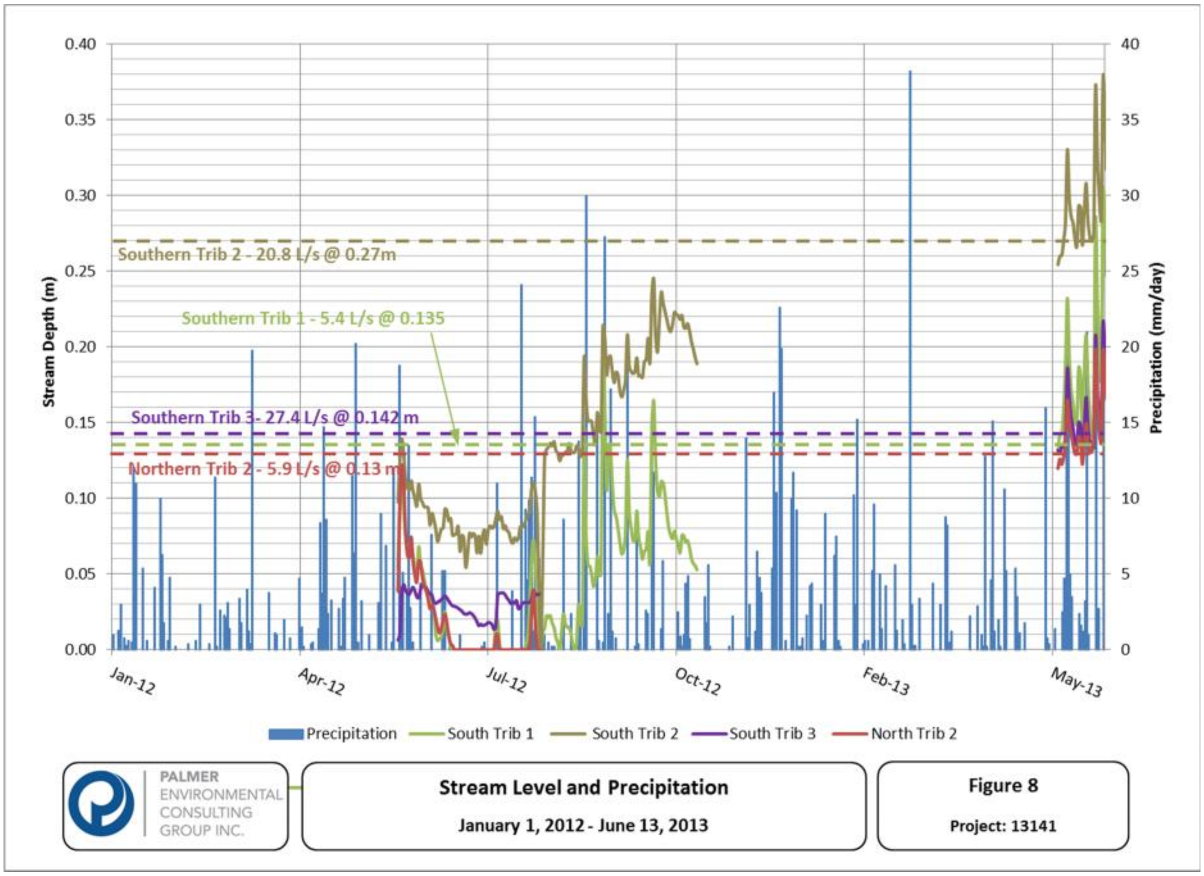


Figure 8 – Stream Level, Precipitation and Flow Data for Baseflow Estimations



4.3.4 Baseflow Contribution from CCV Site

4.3.4.1 Southern Tributary

The majority of the catchment area for the Southern Tributary is located to the south and east of the CCV site (**Figure 7**). The contribution to stream baseflow from these areas will not be affected by the proposed CCV development. The relative contribution from the CCV site to baseflow can be estimated by calculating the average infiltration rate from the area that is *both within the catchment for the Southern Tributary and the CCV site.* This assessment was conducted for the catchment area of South Trib 2 and South Trib 3 stations (shaded areas on **Figure 7**) using the Water Budget estimated baseflow values and presented in **Table 8**. The South Trib 1 station was not included in this analysis because its catchment is located outside of the CCV site boundary.

The results of **Table 8** show that the total infiltration from within the CCV site contributes approximately 0.8 L/s and 0.2 L/s to potential baseflow in the Southern Tributary from within the catchments of South Trib 2 and South Trib 3, respectively. This equates to 32% and 25% of potential baseflow as estimated from the Water Budget shown in **Table 7**. The larger remaining portion of baseflow is primarily derived from groundwater discharge via springs that are connected to the karstic bedrock of the Bobcaygeon Formation located south of the CCV site.

Table 8 - Contribution to Baseflow from the CCV Site – Water Budget

Station	Total Subcatch-ment Area (m^2)	Subcatchment Area within CCV Site (m^2)	Average Infiltration within CCV Site Catchment (mm)	Contribution to Baseflow from CCV Site (L/s)	Estimated Baseflow from Water Budget for Total Subcatchment (L/s) *From Table 7*	Percent Contribution from CCV Site (%)
South Trib 2	500,231	284,733	90	0.8	2.5	32%
South Trib 3	155,051	51,700	122	0.2	0.8	25%
North Trib 2	646,826	646,826	127	2.6	2.6	100%

4.3.4.2 Northern Tributary

A similar analysis to determine the relative contribution to baseflow was conducted for the Northern Tributary. The North Trib 1 station was not included in this analysis because its catchment is located outside of the CCV site boundary. The catchment for the Northern Tributary upstream of North Trib 2 is completely located within the proposed CCV development boundary (shaded area on **Figure 7**) and therefore, 100% of the baseflow in this reach is derived from the CCV site based on the Water Budget analysis (**Table 8**).

As shown in **Table 8**, the average annual infiltration rate for the lands contributing to the subcatchment area measured at North Trib 2 is 127 mm. This value is highly skewed towards the infiltration rate of the Bobcaygeon Formation bedrock IRA (>250 mm) located at the corner of Old Montreal Road and Frank Kenny Road (**Figure 5**). Infiltration from this feature is not interpreted to contribute to stream flow in the Northern Tributary. Infiltration into the Important Recharge Areas located north of the Northern Tributary are primarily located outside of the Northern Tributary sub-catchment with recharge into these areas likely flowing north to the lower reaches of Cardinal Creek and the Ottawa River (Paterson Group Inc., 2013).

No baseflow estimates or water budget analysis was conducted for the area west of La Porte Nursery due to insufficient stream flow monitoring data. The collection of additional data from this reach is included as a monitoring recommendation.

5 Assessment of Impacts

5.1 Groundwater Resources

The CCV site is located on an area dominated by marine clay and bedrock outcrops. The marine clay represents a major aquitard that restricts groundwater flow and infiltration, while the fractured bedrock was found to be solution enhanced and contributes a significant recharge and discharge function within the CCV site.

The majority of the deeper groundwater recharge within the CCV site and surrounding area is likely derived from the Important Recharge Areas (IRAs) (**Figure 5**). Most of the IRAs (**shown in Figure 5**) are located outside of the CCV site and/or will remain as open space in the proposed CCV Concept Plan (**Appendix A**).

The areas that have not been avoided include a small area of shallow Bobcaygeon Formation bedrock that was identified through test pit data on the eastern site boundary south of Old Montreal Road, and portions of the Gull River Formation bedrock outcrop near the current La Porte Nursery and the eastern boundary of the CCV development. Infiltration from these bedrock features is not interpreted to contribute to stream flow in the Northern Tributary as these areas are located outside of the Northern Tributary sub-catchment (**Figures 5** and **7**) and as noted, recharge is interpreted to be flowing north to the lower reaches of Cardinal Creek and the Ottawa River (Paterson Group Inc., 2013).

5.2 Southern Tributary

As discussed in Section 3.2.2, flow in the Southern Tributary while dominated by surface water runoff and inputs from the existing drainage network, has groundwater supported baseflow derived from discrete springs in the middle reaches of the Tributary. Both the middle and lower reaches of the Southern Tributary are considered to be permanently flowing streams supported by this groundwater baseflow. The recharge area that supports these springs is located outside of the CCV boundary and will not be affected by the proposed development.

Local seepage from the upper weathered overburden contributes only a small portion to stream flow and is only prevalent following precipitation events and during the spring/wet seasons. This seepage is not connected to a permanent groundwater source and is not sufficient to sustain stream flow during low flow periods.

Based on the April 9, 2013 version of the JFSA Cardinal Creek Village / Water Balance Analysis, it was assumed that the proposed development would have a total unmitigated imperviousness of 61%. If this area for infiltration is lost, the potential reduction to baseflow in the Southern Tributary is estimated at 0.5 L/s for the South Trib 2 reach and 0.1 L/s for the South Trib 3 reach. These values are based on a 61% reduction in the Water Budget determined baseflow contribution in South Trib 2 and South Trib 3 from *within the CCV site* as presented in **Table 8**. This reduction may be offset through the application of mitigation measures such as those described below and in Section 6.1.

A 30 m buffer around the middle and lower reaches of the Southern Tributary should be put in place to protect the small local seepage contribution. Additionally, the component of baseflow derived from existing agricultural drainage should be maintained through the proposed stormwater management practices. Mitigation measures as described in Section 6.1 should enhance infiltration within the CCV area and are expected to maintain or enhance baseflow to the Southern Tributary.

Overall, the Southern Tributary is not predicted to be adversely affected by the proposed CCV development. This assessment is based on the current Concept Plan (**Appendix A**) which avoids Important Recharge Areas located to the south of the CCV site and provides a 30 m buffer around the permanently flowing watercourse.

5.3 Northern Tributary

As discussed in Section 3.2.3, flow in the Northern Tributary is predominantly derived from surface water runoff and inputs from farm drainage. Only the portion of the Northern Tributary located west of La Porte is supported by small amounts of groundwater discharge interpreted from the Gull River Formation bedrock and from localized seeps. The Concept Plan, as presented in **Appendix A**, shows that this portion of the Northern Tributary west of the La Porte Nursery will be retained post development.

Based on the April 9, 2013 version of the JFSA Cardinal Creek Village / Water Balance Analysis, it was assumed that the proposed development would have a total unmitigated imperviousness of 61%. If this area for infiltration is lost, the potential reduction to baseflow in the Northern Tributary estimated from the Water Budget is 1.6 L/s (61% of 2.6 L/s baseflow as calculated from the Water Budget and presented on **Table 8**). Based on discussions with JFSA (H. Wilson, personal communication, June 11, 2013), tile drainage is planned to be installed around some of the homes of the proposed CCV development. It is our understanding that this mitigation measure will be used to help offset impacts to infiltration.

West of the La Porte Nursery, the Northern Tributary encounters shallow bedrock. As discussed above, this area and the associated groundwater discharge will be maintained post-development as the Concept Plan has designated this area as open space.

Through implementation of stormwater management practices, maintaining open areas in Important Recharge Areas, particularly west of La Porte Nursery, and putting into practice the mitigation measures such as those described in Section 6.1, baseflow in the Northern Tributary is not anticipated to be adversely affected by the proposed CCV development.

5.4 Water Budget

The average annual infiltration rate for the CCV site is 108 mm over its entire area (**Figure 5**). It is important to recognize that over most of the lands proposed to be developed under the Concept Plan, the majority are underlain by low permeability marine clay. The infiltration rate through these soils is expected to be approximately 75 mm, which is much less than the average.

The majority of high infiltration areas or IRAs have been avoided through modifications to the Concept Plan boundary or though leaving the areas as undisturbed open space. Through these actions, most of the important recharge and infiltration features have been protected in the post-development condition and their contribution to water budget will be preserved. The areas that have not been avoided include a small area of shallow Bobcaygeon Formation bedrock that was identified through test pit data on the eastern site boundary south of Old Montreal Road, and most of the Gull River Formation bedrock outcrop near the current La Porte Nursery.

Based on the April 9, 2013 Cardinal Creek Village / Water Balance Analysis Letter, by JFSA, the unmitigated post-development annual infiltration volumes under the proposed conditions would be 61% of existing conditions (or a reduction of 39%). This Letter (JFSA, 2013) could be revised to better reflect the lower recharge value of the developed lands on marine clay and the higher recharge values of the open space lands that are primarily on fractured bedrock. Essentially, an existing infiltration value conservatively estimated to be 75 mm could be applied to the marine clay areas and an existing value ranging from 150 mm to >250 mm could be applied to the open space lands on fractured bedrock. This will better reflect the importance of maintaining infiltration in the high permeability areas and better emulate the pre-to-post conditions.

It is also expected that infiltration can be increased through the implementation of mitigation measures that focus on reducing the area of low permeability marine clay and increasing the area of exposed bedrock or permeable backfill materials. Section 6.1 provides a number of mitigation measures designed to focus mitigation measures where they would be most effective.

6 Mitigation and Monitoring

6.1 Potential Mitigation Measures

The following mitigation measures could be applied to protect the existing function of the groundwater supported natural features on the CCV site and increase infiltration:

- Maintain a 30 m buffer around the middle and lower reaches of the Southern Tributary to protect the local seepage contribution to baseflow.
- Buried services have the potential to increase infiltration through the placement of granular bedding that has a much higher permeability than the existing marine clay or till. Where buried services are placed on bedrock, infiltration and groundwater recharge may be increased from the existing condition depending site specific conditions.

- Design stormwater management and basement tile drains to emulate the contribution of the existing farm drains in conveying infiltration to the Northern Tributary. Most of the Northern Tributary is already an intermittent watercourse, but this will help maintain flow conditions more similarly to its existing condition.

- Areas where site grading or construction decreases the thickness of marine clay or till overlying the bedrock, will have increased infiltration potential relative to the existing condition. Even a small number of perforated pipes placed in rear yards on top of fractured Bobcaygeon Formation bedrock will greatly increase the infiltration and recharge potential of these areas.

- Mitigation measures to increase infiltration (i.e., perforated pipes or pervious land uses) should be focused on areas adjacent to steep changes in elevation, such as stream valleys or bedrock outcrops, where the natural hydraulic gradient is steep and water can move towards discharge areas. Mitigation measures should also be focused on areas that are underlain by permeable soils, such as shallow bedrock. Geotechnical slope stability concerns must be considered if implementing such mitigation measures.

6.1.1 Source Water Protection Conformity

None of the potential mitigation measures contradict the Mississippi-Rideau Source Protection Plan. The source water policies do not apply to simple conveyance systems such as gutters, ditches, swales and culverts, but do apply to larger facilities for the treatment, retention, infiltration or control of stormwater. Based on the author's interpretation, the policies are considered to apply to lot level controls such as perforated drainage pipes.

Many of the higher permeability areas on the CCV site correspond to Highly Vulnerable Aquifers (HVA) within the Mississippi-Rideau Source Protection Area. HVAs are given a Vulnerability score of 6 under Source Water Protection Guidelines. Stormwater management facilities (considered to include perforated pipe drains) are only considered a Significant Threat if they are within a Wellhead Protection Zone (WPZ) with a Vulnerability score of 10 or an Intake Protection Zone (IPZ) with a Vulnerability score of 8 to 10. No WPZ or IPZ exist in the Cardinal Creek Watershed or the CCV site. Therefore, stormwater management facilities are not considered a Significant Threat if placed in HVAs and can be located there with the implementation of best management practices.

6.2 Recommended Monitoring Program

Although no adverse effects are expected from the proposed development, the flow regime of the Northern and Southern tributaries needs to be better characterized to compare to Water Budget estimated baseflow values, and to understand potential long-term changes to surface water flow and the effectiveness of mitigation measures. The baseflow values used in this report are roughly estimated based on best available data. Stream level, temperature and flow monitoring should continue at established stations for 3-years. The data collected must be sufficient to develop a stage-discharge curve at each location to understand the relationship between stream level and flow.

A third surface water monitoring station should be added to the Northern Tributary west of La Porte Nursery and west of the bedrock outcrop, to better characterize groundwater baseflow inputs from the Gull River Formation bedrock.

Groundwater quantity (level) and quality (chemistry) should be monitored in private water wells down gradient of the CCV site. The monitoring program recommended by Paterson (2013) is expected to be sufficient to understand potential impacts to groundwater users.

7 Summary

A Site Specific Water Budget Assessment was conducted by PECG to characterize the groundwater flow conditions and to estimate infiltration and runoff on the proposed Cardinal Creek Village (CCV) development site. This was ultimately completed to understand the relationship between groundwater recharge, and groundwater discharge within surface water features on the CCV site, in order to evaluate the potential impact of the proposed development on these features.

Through a detailed background review of work completed by others, a site visit conducted by Mr. Jason Cole on June 5, 2013, and completing of a GIS-based Water Budget Model, the following conclusions are presented:

- The majority of the site is underlain by low permeability marine clay and till deposits that have a low infiltration potential.
- Areas where solution enhanced bedrock of the Gull River Formation and the Bobcaygeon Formation are present at or near surface, have a high infiltration potential and are considered Important Recharge Areas.
- The majority of high infiltration areas or Important Recharge Areas have been avoided in the proposed Concept Plan or through leaving the areas as undisturbed open space.
- The middle and lower reaches of the Southern Tributary have a permanent baseflow regime that is supported by groundwater discharge from karst springs from the Bobcaygeon Formation bedrock. These karst features are recharged from areas south of the proposed CCV development.
- The Northern Tributary has an intermittent flow regime and is primarily sustained by surface runoff and inputs. West of La Porte Nursery, this tributary receives minor groundwater discharge from the Gull River Formation bedrock.
- The average annual infiltration for the site is 108 mm. The average annual runoff for the site is 184 mm. Areas of marine clay have an assumed annual infiltration of about 75 mm, which is considered to be conservative, while solution enhanced bedrock can be greater than 250 mm.
- The majority of groundwater baseflow to the Southern Tributary is derived from recharge areas located south of the proposed CCV development and will not be affected by the development.
- The majority of flow to the Northern Tributary is presently derived from the existing farm drainage network and runoff from within the CCV site that is expected to be maintained based on the proposed stormwater management design.

- The Important Recharge Areas associated with the Bobcaygeon Formation will not be affected by the proposed development, as most of these areas are outside of the current proposed CCV site. Portions of the Important Recharge Areas in the north and east of the site associated with the Gull River Formation (lower infiltration values relative to the Bobcaygeon) are proposed for development. The recharge derived from these areas is not interpreted to support stream flow or baseflow on the CCV site and is likely flowing towards the lower reaches of Cardinal Creek and the Ottawa River through the bedrock aquifer.
- Baseflow to natural environmental features is not anticipated to be adversely affected by the proposed CCV development due to implementation of stormwater management practices, avoiding development on Important Recharge Areas, and putting in place mitigation measures.
- Additional surface water monitoring and baseflow characterization for 3-years is recommended to further understand the relationship between surface water and groundwater.

8 Statement of Limitations

The scope of our Site Specific Water Budget Assessment was limited to the specific scope of work for which we were retained and that is described in this report. Field borehole logs, borehole locations, and test pit data were previously completed and complied by Paterson Group Inc. (2013). PECG has assumed that the information provided by Paterson (2013) was factual and accurate. The Water Budget Model and data was provided by AECOM and was relied upon in this report. PECG accepts no responsibility for any deficiency, misstatement or inaccuracy contained in this report as a result of omissions, misinterpretations or negligent acts from relied upon data. Judgment has been used by PECG in the interpretation of the information provided but subsurface physical and chemical characteristics may vary between or beyond borehole locations given the variability in geological conditions.

PECG is not a guarantor of the geological or groundwater conditions at the subject site, but warrants only that its work was undertaken and its report prepared in a manner consistent with the level of skill and diligence normally exercised by competent geoscience professionals practicing in the Province of Ontario. Our findings, conclusions and recommendations should be evaluated in light of this limited scope of our work.

Should the Concept Plan discussed herein change for the proposed development, PECG should be allowed an opportunity to revisit the water budget calculations and conclusions provided.

9 References

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10 Glossary of Terms

Aquatic	Refers to an environment that consists of, relates to, or is in water; or to animals and plants living or growing in, on, or near the water.
Aquifer	Rock or soil in a formation that is saturated and sufficiently permeable to transmit water in sufficient quantities to serve as a source of water supply.
Aquitard	Rock or soil in a formation that is saturated but is not sufficiently permeable to transmit water in sufficient quantities to serve as a source of water supply.
Baseflow	The portion of surface water flow in a river or stream that is derived from groundwater discharge.
Bedrock	The solid rock that underlies any unconsolidated sediment or soil.
Boreholes	A hole that is drilled into the subsurface by the cutting of soil and rock and removal of the cuttings from the hole. Can be completed as a monitoring well.
Confined Aquifer	An aquifer that is overlain by deposits with significantly lower permeability (i.e., confining bed or aquitard); thereby confining the waters therein.
Clean Water Act (2006)	The Clean Water Act (2006) helps protect drinking water at the source, as part of an overall commitment to safeguard human health and the environment. A key focus of the legislation is the preparation of locally developed, science-based assessment reports and source protection plans. (*reference* - http://www.ene.gov.on.ca/environment/en/subject/protection/STDPROD_080600.html)
Drainage Area	An area from which all precipitation flows to a single stream or set of streams.
Ecological Land Classification (ELC)	A system to delineate natural regions based on ecological factors. In Ontario, the Ministry of Natural Resources defines ecological units on the basis of bedrock, climate, physiography, and corresponding vegetation, creating an Ecological Land Classification System.
Environmental Effect	The effect that a proposed undertaking or its alternatives has or could potentially have on the environment, either positive or negative, direct or indirect, short- or long-term.
Evapotranspiration (ET)	The amount of water lost to the atmosphere through the combined effect of evaporation and plant transpiration.
Fractures	A natural "break" in the bedrock along weaknesses in the rock matrix. Fractures can generally be described as horizontal or "bedding plane" fractures or vertical/ sub-vertical fractures.
Geographic Information System (GIS)	A system for creating, storing, analyzing and managing spatial data and associated attributes.
Greater Cardinal Creek Subwatershed Existing Conditions Report and	Conducted by AECOM in 2009 and revised in 2013. A subwatershed or regional scale collaborative approach to collecting, analyzing and disseminating water resource data as a basis for effective stewardship of water resources within the Cardinal Creek Subwatershed.

Management Plan	
Groundwater	Water below the surface of the ground that occupies a zone of the earth's mantle that is saturated with water.
Groundwater Discharge	The amount of water that leaves the groundwater system and enters the surface water system through upwards movement. Generally occurs in lowland area where the water table intercepts the ground surface. Can occur at springs.
Groundwater Recharge	The amount of water from precipitation that passes through the unsaturated zone and enters the groundwater system below the water table. Generally occurs in upland areas.
Groundwater/ Surface Water Interactions	A general term used to describe as types of processes between the groundwater system and the surface water system, including groundwater discharge, springs and seepage.
Habitat	The physical location or type of environment in which an organism or biological population occurs or lives, grows, and carries out life processes.
Headwaters	The source of water at the top of a drainage system.
Highly Vulnerable Aquifers (HVA)	Part of Source Water Protection Technical Rules. Defined as areas where the soil is very thin or absent and the underlying bedrock contains secondary porosity features that make the groundwater vulnerable to surface contaminants.
Infiltration	The amount of precipitation that enters the subsurface or soil layer. Does not need to reach the water table (see groundwater recharge).
Infiltration Factors	Originally derived from MOEE (1995). Based on topography, vegetation and soil type. Describe the "relative" difference in infiltration between different areas of soil with similar characteristics.
Interflow	Precipitation that enters the shallow subsurface and moves laterally towards surface water bodies without recharging the groundwater system.
Joints	A natural "break" in the bedrock along points of stress in the rock related to the regional stress condition at the time of deposition.
Karst	A distinctive bedrock terrain attributable to dissolution of highly soluble carbonate rock such as limestone, dolostone or gypsum. Groundwater flow through karst systems is typically though solution enhanced secondary porosity features.
Laminar flow	Flow in a pipe or channel that flows in parallel layers, with no disruption between the layers. It is the opposite of turbulent flow.
Macro Karst Features	A general term that refers to larger karst features such as solution caves, sinking streams, springs, or large enclosed depressions (Worthington and Ford, 2009).
Micro Karst Features	A general term that refers to small karst features such as bedrock pavements and solution enhanced organized channels (Worthington and Ford, 2009).
Mississippi-Rideau Source Protection Area	The Mississippi-Rideau Source Protection Area is 8,500 km2 and is made up of the jurisdictions of the Mississippi Valley and Rideau Valley Conservation Authorities. These jurisdictions encompass lands that drain into the Mississippi and Rideau Rivers and then into the Ottawa River (*reference – Mississippi-Rideau Source Protection Plan, 2013)*

Mitigation measure/techniques	Action(s) that remove or alleviate to some degree the negative effects associated with the implementation of an alternative.
Monitoring	A systematic method for collecting information using standard observations according to a schedule and over a sustained period of time.
Monitoring Well or Groundwater Monitor	A borehole that has been completed to take measurements of the water table. Usually completed using 2" diameter PVC pipe with thin slots (screen) to allow groundwater enter the well but prohibit soil partials.
Natural Environment	A term that encompasses all living and non-living things occurring naturally on Earth or some region thereof.
Ontario Water Resources Act (OWRA)	The *OWRA* provides for the conservation, protection and management of Ontario's waters and for their efficient and sustainable use to promote Ontario's long-term environmental, social and economic well-being.
Permeability	Pertaining to the relative ease with which a medium can transmit a liquid under a hydraulic or potential gradient. For example, sand and gravel deposits have a high permeability and silt and clay deposits have a low permeability.
Physiographic region	Refers to a distinctive area of landscape that has its own topography and geology.
Potential Effect	An effect that is deemed possible to result from an activity or implementation of a particular alternative.
Potentiometric Surface	The surface that represents the level to which water will rise in a well.
Review agencies	Means government agencies, ministries, or public authorities or bodies whose mandates require them to have jurisdiction over matters affected or potentially affected by projects. This includes municipalities other than the proponent.
Runoff	More correctly called surface runoff or overland flow. The amount of precipitation falling on the land that moves based on topography as a sheet or as small channels directly on the ground surface towards surface water bodies. Occurs when precipitation exceeds the infiltration capacity of the soil.
Secondary Porosity	Porosity is a measure of the amount of void or pore space between soil grains or within the rock matrix. Secondary porosity refers to the void space created by fractures, joints, root holes or weathering.
Seepage	For the purposes of this report, seepage is defined as the movement of water from the unsaturated zone (i.e., via interflow) into a surface water body. It is also referred to as the lateral or downwards movement of water into a watercourse or low lying area. This term does not imply a connection to the water table or saturated zone.
Soil Moisture Holding Capacity	The amount of soil moisture or water content held in soil after excess water has drained away.
Significant Groundwater Recharge Area (SGRA)	Part of Source Water Protection Planning Technical Rules. Defined as areas that allow a significant amount of precipitation or snowmelt to recharge the water table.
Site Specific	An assessment that only considers a particular area in question. Can also include the immediate surrounding area or any other area that influences the

	conditions on the particular site.
Solution Enhanced	Existing secondary porosity features such as fractures and joints that have been enlarged or enhanced through the natural dissolution of carbonate rock.
Source Water Protection	Source Water refers to the lakes, rivers and aquifers from which we obtain the water we drink and use. Source Water Protection is derived from the Clean Water Act (2006).
Species at Risk (SAR)	A Canadian Federal law that seeks to prevent Canadian indigenous species, subspecies, and distinct populations from becoming extirpated or extinct, to provide for the recovery of endangered or threatened species, and encourage the management of other species to prevent them from becoming at risk.
Spring	The upwards movement of water from the saturated zone into a surface water body at a discrete point or location. The movement of groundwater from a confined aquifer into the surface water system, again from a discrete point or location.
Surface Water	Water that exists above the substrate or soil surface, including runoff from precipitation events and snow melt, typically occurring in streams, creeks, rivers, lakes, ponds and wetlands.
Surplus	In reference to the surplus of water remaining after subtracting the mean annual evapotranspiration from the average precipitation. This amount of water (usually shown in mm or mm/year) is the amount of water available for infiltration or runoff.
Terrestrial	Refers to animals and plants living or growing on the ground (land), as opposed to animals and plants living in aquatic environments. Specifically referring to habitats where the water table is rarely or briefly above the surface and where soils are not saturated with water.
Test Pit	A large diameter hole or pit excavated using a backhoe.
Till	Glacial drift composed of an unconsolidated, heterogeneous mixture of clay, sand, pebbles, cobbles, and boulders.
Unconfined Aquifer	An aquifer in which there are no confining beds (layers) between the zone of saturation and the surface (commonly referred to a water table aquifer).
Unsaturated Zone	The area below the ground surface, but above the water table, that is not saturated with respect to water. Pore spaces in the unsaturated zone predominantly filled with air.
Water Balance	Describes the difference or remainder or surplus of water between precipitation and potential evapotranspiration (ET) for a given area. It is defined as: $S = P - ET$ Where: S = Surplus or the amount of precipitation (P) remaining after a portion is naturally lost to evaporation and plant transpiration (ET).
Water Budget	Describes the movement of water in and out of a watershed. Takes into account all components of the hydrological cycle. It is defined as: $Q_{out} = P - ET - I - RO - \Delta S_{sw} - \Delta S_{gw}$ Where: Q_{out} = surface water flow out of the watershed

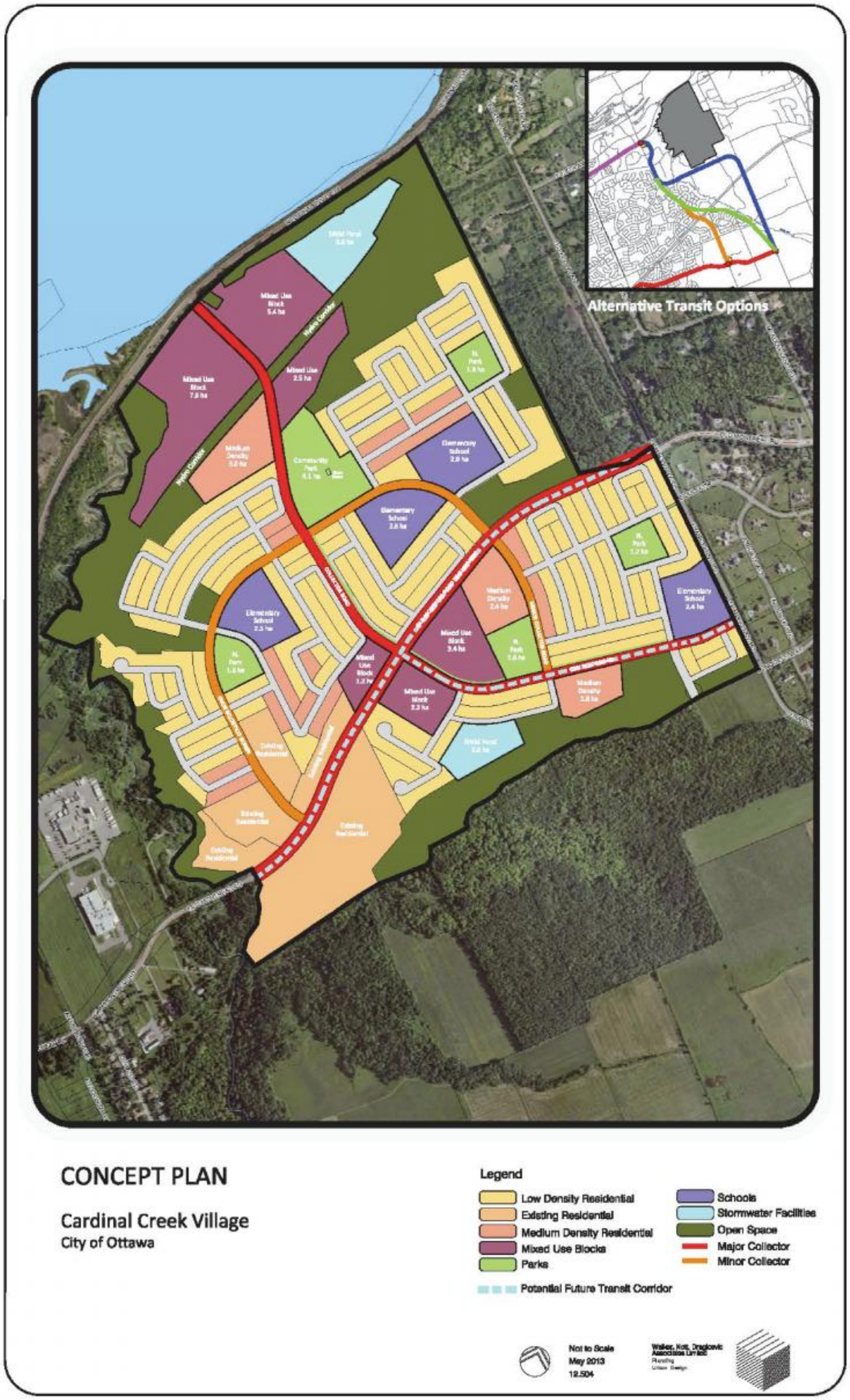
	P = precipitation ET = evapotranspiration RO = runoff ΔS_{sw} = change in surface water storage ΔS_{gw} = change in groundwater storage
Watercourse	A body of water having defined bed and banks with permanent or intermittent flow that may include rivers, creeks, streams, and springs.
Watersheds	An area that is drained by a river and its tributaries.
Wetland	Lands that are seasonally or permanently covered by shallow water, as well as lands where the water table is close to or at the surface. In either case the presence of abundant water has caused the formation of soils saturated with water and has favoured the dominance of either hydrophytic plants or water tolerant plants. The four major types of wetlands are swamps, marshes, bogs, and fens.

Appendix A

Cardinal Creek Village Concept Plan

- **Figure A1 - Concept Plan June 2013**

Figure A1

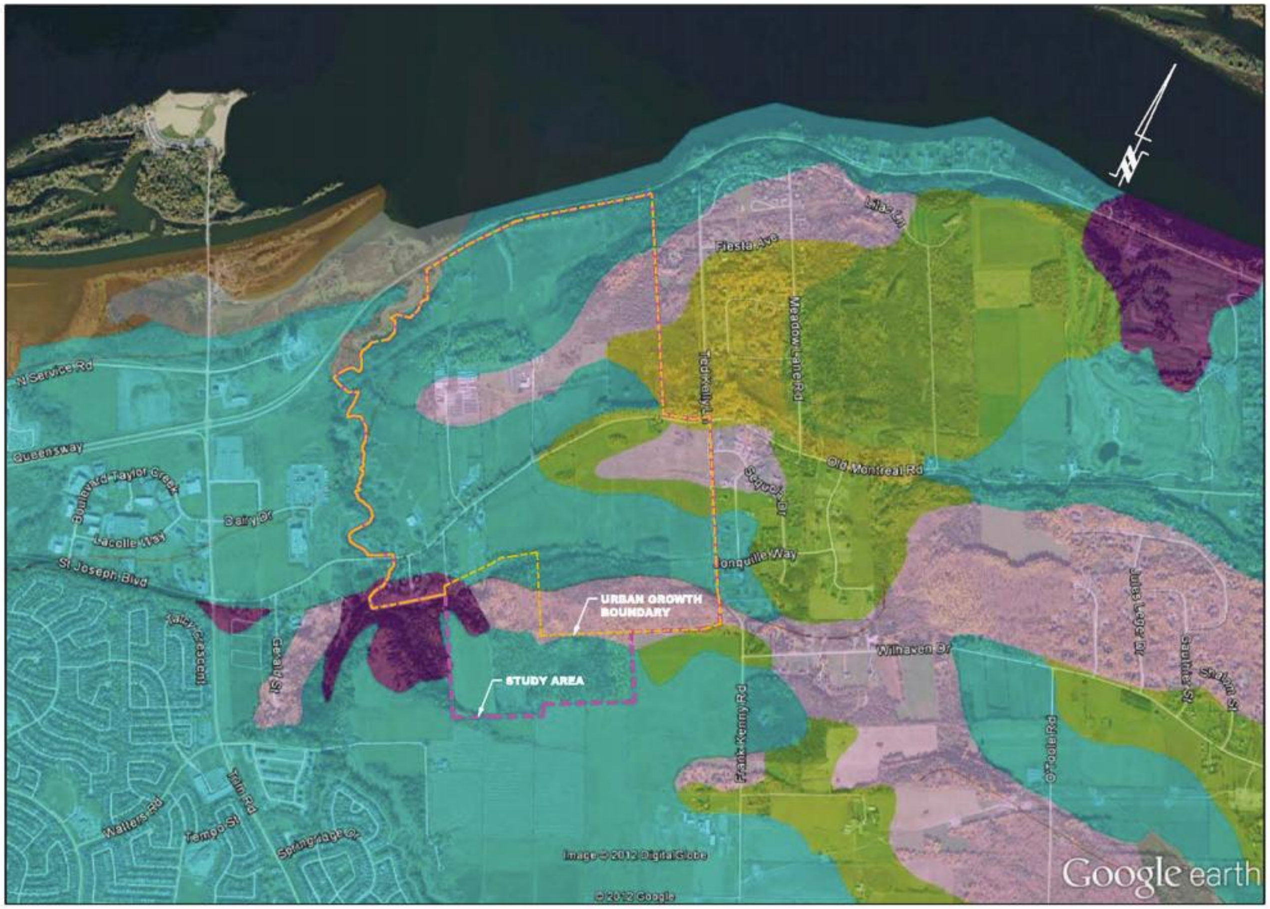

Alternative Transit Options
Mixed Use Block 5.4 ha
Mixed Use Block 7.8 ha
Mixed Use 2.5 ha
SWM Pond 3.8 ha
Hydro Corridor
Hydro Corridor
Medium Density 3.2 ha
Community Park 4.1 ha
N. Park 1.8 ha
Elementary School 2.9 ha
Elementary School 2.6 ha
Elementary School 2.5 ha
Elementary School 2.4 ha
N. Park 1.2 ha
N. Park 1.6 ha
N. Park 1.8 ha
Medium Density 2.4 ha
Medium Density 1.8 ha
Mixed Use Block 3.4 ha
Mixed Use Block 1.2 ha
Mixed Use Block 2.2 ha
SWM Pond 2.0 ha
Collector Road
Existing Residential
Existing Residential
Existing Residential
Existing Residential
CONCEPT PLAN
Cardinal Creek Village
City of Ottawa
Legend
Low Density Residential
Existing Residential
Medium Density Residential
Mixed Use Blocks
Parks
Schools
Stormwater Facilities
Open Space
Major Collector
Minor Collector
Potential Future Transit Corridor
Not to Scale
May 2013
12.504
Walker, Nott, Dragicevic Associates Limited
Planning
Urban Design

Appendix B

Geology

- **Figure B1 - Surficial Geology (Paterson, 2013)**
- **Figure B2 - Bedrock Geology (Paterson, 2013)**
- **Figure B3 - Cross Section with Groundwater Flow (Cross Section Geology from Paterson, 2013)**

Figure B1



NOTE: INFORMATION REPRODUCED FROM ONTARIO GEOLOGICAL SURVEY G.I.S. OVERLAY FOR GOOGLE EARTH
REFERENCE SHOULD BE MADE TO SITE SPECIFIC GEOTECHNICAL INVESTIGATION FINDINGS BY PATERSON GROUP INC.

p:\autocad drawings\hydrogeology\ph18xx\ph1890 - cardinal village\ph1890-feb 22-2013\ph1890-figures.dwg

LEGEND:

- ■ MODERN ALLUVIAL DEPOSITS
- ■ ORGANIC DEPOSITS
- ■ FINE-TEXTURED GLACIOMARINE DEPOSITS
- ■ COARSE-TEXTURED GLACIOMARINE DEPOSITS
- ■ PALEOZOIC BEDROCK
- ■ TILL
- ■ COLLUVIAL DEPOSITS
- ▬ ▬ STUDY AREA
- ▬ ▬ URBAN GROWTH BOUNDARY

Client:

TAMARACK (QUEEN STREET) CORPORATION

Consultant:

patersongroup
consulting engineers

Project:

HYDROGEOLOGICAL INVESTIGATION

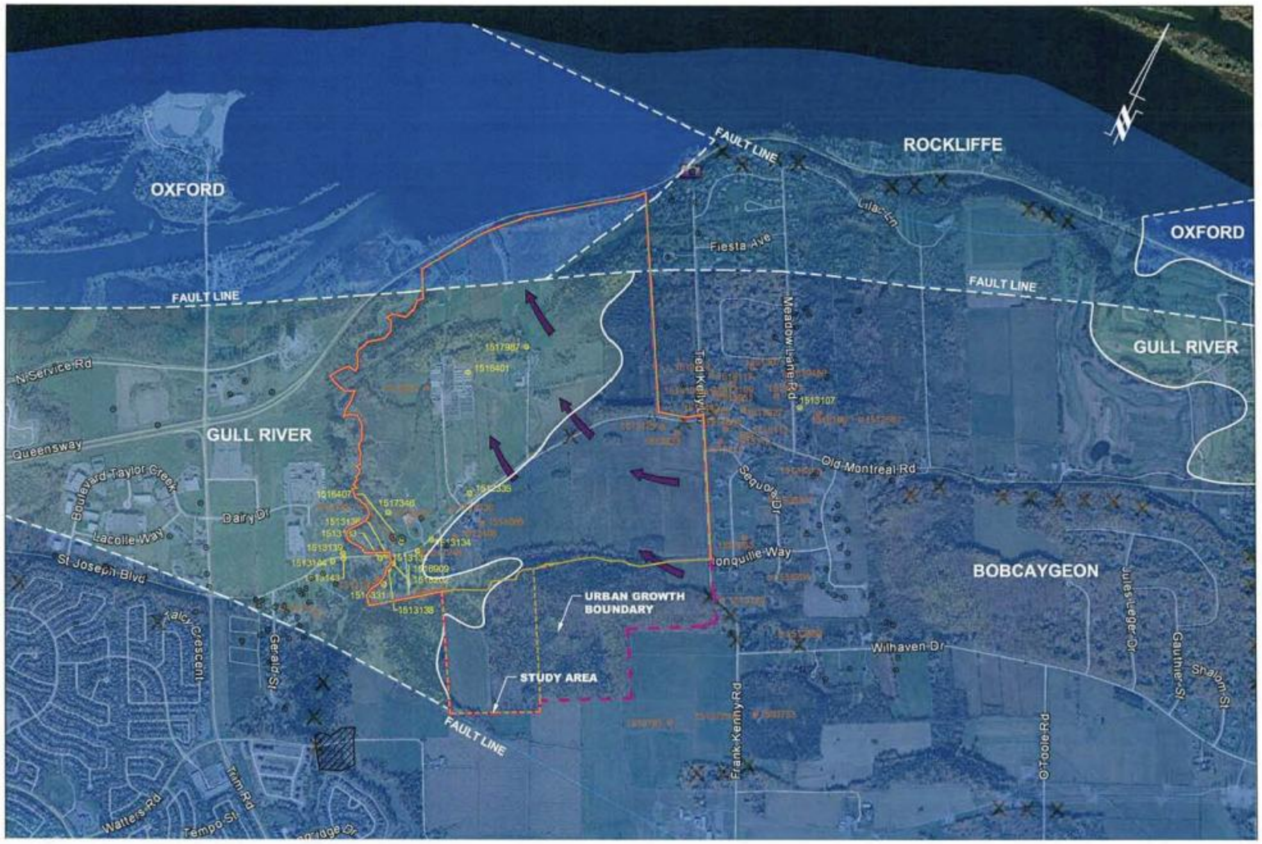
CARDINAL CREEK VILLAGE
OTTAWA, ONTARIO

Drawing:

SURFICIAL SOIL DELINEATION MAPPING

Scale: N.T.S.
Seal:
Date: 02/2013
Drawn by: RAP
Checked by: AVS
File: PH1890
Drawing No.: **PH1890-FIG.2**

Figure B2



NOTE: BEDROCK INFORMATION REPRODUCED FROM ONTARIO GEOLOGICAL SURVEY G.I.S. OVERLAY FOR GOOGLE EARTH
WATER WELL INFORMATION REPRODUCED FROM THE ONTARIO GROUND WATER INFORMATION NETWORK (GIN)

LEGEND:

🟦	OXFORD
🟦	ROCKLIFFE
🟦	GULL RIVER
🟦	BOBCAYGEON
▨	APPROXIMATE LOCATION OF KARST AREA (2009) - AS PER GOLDER ASSOCIATES LTD. REPORT No. 09-1127-0086
⊙	UPPER AQUIFER WATER WELL (<80ft) (PUBLISHED MOE RECORDS)
⊙	LOWER AQUIFER WATER WELL (>80ft) (PUBLISHED MOE RECORDS)
⊙	WATER WELL RECORD (PUBLISHED MOE RECORDS)
←	LOCAL DIRECTION OF GROUNDWATER FLOW IN OVERBURDEN AND UPPER BEDROCK AQUIFER

Client:
TAMARACK (QUEEN STREET) CORPORATION

Consultant:
patersongroup
consulting engineers

Project:
HYDROGEOLOGICAL INVESTIGATION
CARDINAL CREEK VILLAGE OTTAWA, ONTARIO

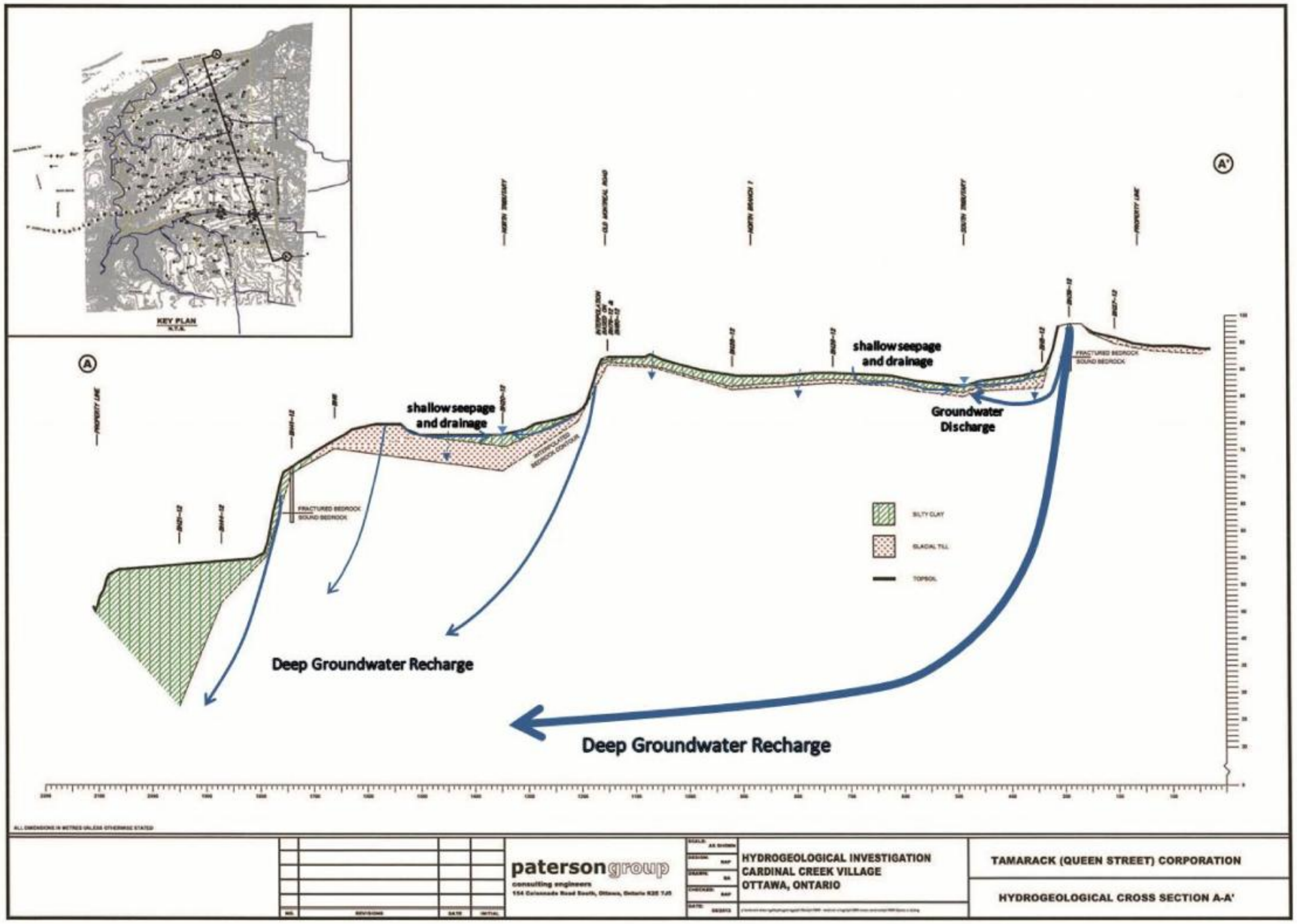
Drawing:
REGIONAL BEDROCK MAPPING

Scale: N.T.S.
Date: 06/2013
Drawn by: BA
Checked by: RAP
File: PH1890
Seal:

Drawing No.:
PH1890-FIG.3

p:\autocad drawings\hydrogeology\ph18xx\ph1890 - cardinal village\ph1890-may 2013\ph1890-figures.dwg

Figure B3


KEY PLAN
N.T.S.
A
A'
PROPERTY LINE
NORTH TRIBUTARY
OLD MONTREAL ROAD
NORTH BRANCH 1
SOUTH TRIBUTARY
PROPERTY LINE
shallow seepage and drainage
shallow seepage and drainage
Groundwater Discharge
Deep Groundwater Recharge
Deep Groundwater Recharge
FRACTURED BEDROCK
SOUND BEDROCK
INTERPOLATED BEDROCK CONTOUR
SILTY CLAY
GLACIAL TILL
TOPSOIL
ALL DIMENSIONS IN METRES UNLESS OTHERWISE STATED
patersongroup
consulting engineers
154 Colonnade Road South, Ottawa, Ontario K2E 7J5
SCALE: AS SHOWN
HYDROGEOLOGICAL INVESTIGATION
CARDINAL CREEK VILLAGE
OTTAWA, ONTARIO
TAMARACK (QUEEN STREET) CORPORATION
HYDROGEOLOGICAL CROSS SECTION A-A'
NO.
REVISIONS
DATE
INITIAL

Appendix C

Water Balance Raw Data – Ottawa CDA Station

- 50 mm Soil Moisture
- 100 mm Soil Moisture
- 200 mm Soil Moisture
- 300 mm Soil Moisture
- 400 mm Soil Moisture

```
Ottawa CDA, ON          WATER BUDGET MEANS FOR THE PERIOD 1900-2005   DC20492

   LAT.... 45.38     WATER HOLDING CAPACITY... 50 MM     HEAT INDEX... 36.25
   LONG... 75.72     LOWER ZONE............... 30 MM     A............ 1.073

 DATE   TEMP (C)  PCPN  RAIN  MELT   PE    AE   DEF   SURP  SNOW  SOIL  ACC P

31- 1  -10.9      65     9    12     0     0     0    21    89    50    284
28- 2   -9.8      55     8    13     0     0     0    21   123    50    339
31- 3   -3.2      65    30    78     5     5     0   103    80    50    404
30- 4    5.5      66    63    84    31    31     0   116     0    49    470
31- 5   12.9      74    74     0    79    77    -2    14     0    33    544
30- 6   18.2      85    85     0   116   100   -16     3     0    14    629
31- 7   20.7      85    85     0   135    94   -41     0     0     5    713
31- 8   19.4      80    80     0   117    78   -39     1     0     6    793
30- 9   14.8      81    81     0    76    66   -10     3     0    18    875
31-10    8.3      73    73     1    37    37    -1    19     0    35     73
30-11    1.1      74    58     8    10    10     0    43     9    48    147
31-12   -7.4      72    21    14     1     1     0    32    46    50    220
AVE      5.8 TTL 877   667   210   607   499  -109   376


Ottawa CDA, ON          STANDARD DEVIATIONS FOR THE PERIOD 1900-2005  DC20492

 DATE   TEMP (C)  PCPN  RAIN  MELT   PE    AE   DEF   SURP  SNOW  SOIL  ACC P

31- 1    2.9      26    12    15     0     0     0    24    50     1     60
28- 2    2.8      25    12    19     1     1     0    27    66     1     64
31- 3    2.6      29    23    55     4     4     0    66    91     0     73
30- 4    1.9      28    28    93     9     9     0    97     4     3     83
31- 5    1.8      36    36     4    12    11     8    25     0    18     97
30- 6    1.2      36    36     0     9    22    23    12     0    18    104
31- 7    1.2      33    33     0     8    30    33     4     0    12    110
31- 8    1.4      39    39     0     9    30    32     8     0    13    121
30- 9    1.4      34    34     0     8    15    16    12     0    19    124
31-10    1.5      36    36     2     7     7     2    26     0    19     36
30-11    1.9      29    31    10     4     4     0    32    13     7     45
31-12    3.0      28    19    14     1     1     0    28    36     2     55
```

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Ottawa CDA, ON          WATER BUDGET MEANS FOR THE PERIOD 1900-2005   DC20492

   LAT.... 45.38     WATER HOLDING CAPACITY...100 MM     HEAT INDEX... 36.25
   LONG... 75.72     LOWER ZONE............... 60 MM     A............ 1.073

 DATE   TEMP (C)  PCPN  RAIN  MELT   PE    AE   DEF   SURP  SNOW  SOIL  ACC P

31- 1  -10.9     65    9   12    0    0    0   19   89   97   284
28- 2   -9.8     55    8   13    0    0    0   20  123   98   339
31- 3   -3.2     65   30   78    5    5    0  101   80  100   404
30- 4    5.5     66   63   84   31   31    0  116    0   99   470
31- 5   12.9     74   74    0   79   79    0   14    0   81   544
30- 6   18.2     85   85    0  116  112   -4    3    0   50   629
31- 7   20.7     85   85    0  135  113  -22    0    0   22   713
31- 8   19.4     80   80    0  117   84  -32    1    0   16   793
30- 9   14.8     81   81    0   76   67   -9    1    0   30   875
31-10    8.3     73   73    1   37   37   -1    7    0   59    73
30-11    1.1     74   58    8   10   10    0   27    9   88   147
31-12   -7.4     72   21   14    1    1    0   27   46   95   220
AVE      5.8 TTL  877  667  210  607  539  -68  336


Ottawa CDA, ON          STANDARD DEVIATIONS FOR THE PERIOD 1900-2005  DC20492

 DATE   TEMP (C)  PCPN  RAIN  MELT   PE    AE   DEF   SURP  SNOW  SOIL  ACC P

31- 1    2.9     26   12   15    0    0    0   23   50   10    60
28- 2    2.8     25   12   19    1    1    0   27   66    8    64
31- 3    2.6     29   23   55    4    4    0   64   91    4    73
30- 4    1.9     28   28   93    9    9    0   95    4    3    83
31- 5    1.8     36   36    4   12   12    0   25    0   23    97
30- 6    1.2     36   36    0    9   12   11   12    0   33   104
31- 7    1.2     33   33    0    8   26   28    4    0   28   110
31- 8    1.4     39   39    0    9   29   31    6    0   26   121
30- 9    1.4     34   34    0    8   15   15   10    0   30   124
31-10    1.5     36   36    2    7    7    2   20    0   34    36
30-11    1.9     29   31   10    4    4    0   30   13   20    45
31-12    3.0     28   19   14    1    1    0   28   36   12    55
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Ottawa CDA, ON          WATER BUDGET MEANS FOR THE PERIOD 1900-2005   DC20492

  LAT.... 45.38     WATER HOLDING CAPACITY...200 MM     HEAT INDEX... 36.25
  LONG... 75.72     LOWER ZONE...............120 MM     A............ 1.073

 DATE   TEMP (C)  PCPN  RAIN  MELT   PE    AE   DEF   SURP  SNOW  SOIL  ACC P

31- 1  -10.9      65     9    12     0     0     0    13    89   182    284
28- 2   -9.8      55     8    13     0     0     0    16   123   187    339
31- 3   -3.2      65    30    78     5     5     0    92    80   198    404
30- 4    5.5      66    63    84    31    31     0   114     0   199    470
31- 5   12.9      74    74     0    79    79     0    14     0   181    544
30- 6   18.2      85    85     0   116   116     0     3     0   146    629
31- 7   20.7      85    85     0   135   132    -3     0     0    99    713
31- 8   19.4      80    80     0   117   103   -13     1     0    75    793
30- 9   14.8      81    81     0    76    71    -5     1     0    85    875
31-10    8.3      73    73     1    37    37     0     5     0   116     73
30-11    1.1      74    58     8    10    10     0    14     9   158    147
31-12   -7.4      72    21    14     1     1     0    17    46   175    220
AVE      5.8 TTL 877   667   210   607   585   -21   290


Ottawa CDA, ON          STANDARD DEVIATIONS FOR THE PERIOD 1900-2005  DC20492

 DATE   TEMP (C)  PCPN  RAIN  MELT   PE    AE   DEF   SURP  SNOW  SOIL  ACC P

31- 1    2.9      26    12    15     0     0     0    22    50    29     60
28- 2    2.8      25    12    19     1     1     0    26    66    26     64
31- 3    2.6      29    23    55     4     4     0    63    91    12     73
30- 4    1.9      28    28    93     9     9     0    92     4     3     83
31- 5    1.8      36    36     4    12    12     0    25     0    23     97
30- 6    1.2      36    36     0     9     9     0    12     0    39    104
31- 7    1.2      33    33     0     8    11     9     4     0    50    110
31- 8    1.4      39    39     0     9    18    19     6     0    53    121
30- 9    1.4      34    34     0     8    11    11    10     0    55    124
31-10    1.5      36    36     2     7     7     1    18     0    55     36
30-11    1.9      29    31    10     4     4     0    25    13    44     45
31-12    3.0      28    19    14     1     1     0    25    36    35     55
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Ottawa CDA, ON          WATER BUDGET MEANS FOR THE PERIOD 1900-2005   DC20492

  LAT.... 45.38     WATER HOLDING CAPACITY...300 MM     HEAT INDEX... 36.25
  LONG... 75.72     LOWER ZONE...............180 MM     A............ 1.073

 DATE   TEMP (C)  PCPN  RAIN  MELT   PE    AE   DEF   SURP  SNOW  SOIL  ACC P

31- 1  -10.9      65     9    12     0     0     0    12    89   271    284
28- 2   -9.8      55     8    13     0     0     0    14   123   278    339
31- 3   -3.2      65    30    78     5     5     0    86    80   295    404
30- 4    5.5      66    63    84    31    31     0   111     0   299    470
31- 5   12.9      74    74     0    79    79     0    14     0   281    544
30- 6   18.2      85    85     0   116   116     0     3     0   246    629
31- 7   20.7      85    85     0   135   135     0     0     0   196    713
31- 8   19.4      80    80     0   117   112    -4     1     0   163    793
30- 9   14.8      81    81     0    76    73    -2     1     0   170    875
31-10    8.3      73    73     1    37    37     0     5     0   201     73
30-11    1.1      74    58     8    10    10     0    14     9   243    147
31-12   -7.4      72    21    14     1     1     0    15    46   263    220
AVE      5.8 TTL 877   667   210   607   599    -6   276


Ottawa CDA, ON          STANDARD DEVIATIONS FOR THE PERIOD 1900-2005  DC20492

 DATE   TEMP (C)  PCPN  RAIN  MELT   PE    AE   DEF   SURP  SNOW  SOIL  ACC P

31- 1    2.9      26    12    15     0     0     0    21    50    42     60
28- 2    2.8      25    12    19     1     1     0    25    66    38     64
31- 3    2.6      29    23    55     4     4     0    64    91    18     73
30- 4    1.9      28    28    93     9     9     0    90     4     3     83
31- 5    1.8      36    36     4    12    12     0    25     0    23     97
30- 6    1.2      36    36     0     9     9     0    12     0    39    104
31- 7    1.2      33    33     0     8     8     2     4     0    55    110
31- 8    1.4      39    39     0     9    11     9     6     0    66    121
30- 9    1.4      34    34     0     8     8     6    10     0    70    124
31-10    1.5      36    36     2     7     7     0    17     0    67     36
30-11    1.9      29    31    10     4     4     0    24    13    57     45
31-12    3.0      28    19    14     1     1     0    24    36    48     55
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Ottawa CDA, ON          WATER BUDGET MEANS FOR THE PERIOD 1900-2005   DC20492

  LAT.... 45.38    WATER HOLDING CAPACITY...400 MM     HEAT INDEX... 36.25
  LONG... 75.72    LOWER ZONE...............240 MM     A............ 1.073

 DATE   TEMP (C)  PCPN  RAIN  MELT   PE    AE   DEF   SURP  SNOW  SOIL  ACC P

31- 1  -10.9      65     9    12     0     0     0    11    89   366    284
28- 2   -9.8      55     8    13     0     0     0    13   123   374    339
31- 3   -3.2      65    30    78     5     5     0    84    80   393    404
30- 4    5.5      66    63    84    31    31     0   109     0   399    470
31- 5   12.9      74    74     0    79    79     0    14     0   380    544
30- 6   18.2      85    85     0   116   116     0     3     0   346    629
31- 7   20.7      85    85     0   135   135     0     0     0   296    713
31- 8   19.4      80    80     0   117   116    -1     1     0   260    793
30- 9   14.8      81    81     0    76    75    -1     1     0   265    875
31-10    8.3      73    73     1    37    37     0     5     0   296     73
30-11    1.1      74    58     8    10    10     0    14     9   338    147
31-12   -7.4      72    21    14     1     1     0    15    46   358    220
AVE      5.8 TTL 877   667   210   607   605    -2   270


Ottawa CDA, ON          STANDARD DEVIATIONS FOR THE PERIOD 1900-2005  DC20492

 DATE   TEMP (C)  PCPN  RAIN  MELT   PE    AE   DEF   SURP  SNOW  SOIL  ACC P

31- 1    2.9      26    12    15     0     0     0    21    50    48     60
28- 2    2.8      25    12    19     1     1     0    24    66    43     64
31- 3    2.6      29    23    55     4     4     0    65    91    23     73
30- 4    1.9      28    28    93     9     9     0    90     4     3     83
31- 5    1.8      36    36     4    12    12     0    25     0    23     97
30- 6    1.2      36    36     0     9     9     0    12     0    39    104
31- 7    1.2      33    33     0     8     8     0     4     0    55    110
31- 8    1.4      39    39     0     9     9     3     6     0    70    121
30- 9    1.4      34    34     0     8     8     3    10     0    76    124
31-10    1.5      36    36     2     7     7     0    17     0    73     36
30-11    1.9      29    31    10     4     4     0    24    13    63     45
31-12    3.0      28    19    14     1     1     0    23    36    54     55
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Appendix D

Stream Flow Measurement Data

- **Southern Tributary**
- **Northern Tributary**

APPENDIX D1 - Southern Tributary Flow Estimates

Reference - US EPA Methods

Flow Test Results

FLOW = ALC/T

A = area (triangle or rectangle used depending upon stream shape
L = length
C = roughness coefficient (silty bottoms have more drag than hard bottoms
T = time

Southern Tributary

South Trib 1

test	length (m)	time (s)	velocity (m/s)
1	2.4	15.1	0.16
2	2.4	14.8	0.16
3	2.4	14.8	0.16
AVG	2.4	14.9	0.16
Avg Width	0.805 m		
Avg Depth	0.09 m		
Area	0.04 m^2		
C	0.90		
FLOW	0.01 m^3/s		
	5.3 L/s		

sandysilty bottom
run section

South Trib 2

test	length (m)	time (s)	velocity (m/s)
1	2.5	40.1	0.06
2	3.5	33.1	0.11
3	3.5	42.4	0.08
4	3.5	45	0.08
5	3.5	40.2	0.09
AVG	3.3	40.2	0.08
Avg Width	1.75 m		
Avg Depth	0.34 m		
Area	0.30		
C	0.85		
FLOW	0.02 m^3/s		
	20.8 L/s		

silty/organic bottom
run sectio

South Trib 3

test	length (m)	time (s)	velocity (m/s)
1	3	13.3	0.23
2	3	15.2	0.20
3	3	14.7	0.20
AVG	3	13.4	0.21
Avg Width	0.98 m		
Avg Depth	0.25 m		
Area	0.12 m^2		
C	1.00		
FLOW	0.03 m^3/s		
	27.4 L/s		

hard clay bottom
run section

South Trib 4

test	length (m)	time (s)	velocity (m/s)
1	2.5	7.8	0.32
2	2.5	7.7	0.32
3	2.5	7.7	0.32
AVG	2.5	7.7	0.32
Avg Width	0.79 m		
Avg Depth	0.06 m		
Area*	0.05 m^2		
C	0.90		
FLOW	0.01 m^3/s		
	13.8 L/s		

sandy/ gravel bottom
run section
*square shaped area

Northern Branch

test	length (m)	time (s)	velocity (m/s)
1	1	5.4	0.19
2	1	4	0.25
3	1	4.1	0.24
AVG	1	4.5	0.23
Avg Width	0.45 m		
Avg Depth	0.032 m		
Area	0.01 m^2		
C	0.90		
FLOW	0.00 m^3/s		
	1.4 L/s		

silty bottom
riffle section

Mid Branch 2

test	length (m)	time (s)	velocity (m/s)
1	1	4	0.25
2	1	3.8	0.26
3	1	4.5	0.22
AVG	1	4.1	0.25
Avg Width	0.21 m		
Avg Depth	0.05 m		
Area	0.011 m^2		
C	1.000		
FLOW	0.00 m^3/s		
	2.6 L/s		

hard bottom
riffle section
*square shaped area

APPENDIX D2 - Northern Tributary Flow Estimates

Reference - US EPA Methods

Flow Test Results

FLOW = ALC/T

A = area (triangle or rectangle used depending upon stream shape)
L = length
C = roughness coefficient (silty bottoms have more drag than hard bottoms)
T = time

Northern Tributary

North Trib 1

test	length (m)	time (s)	velocity (m/s)
Flow estimate taken from Ted Kelly Rd.			
Channel full of vegetation			
No stream flow measurement taken			
Flow estimated at ~1 L/s			
AVG	-		
Avg Width	-	m	
Avg Depth	-	m	
Area	-	m^2	
C	-		
FLOW	-	m^3/s	
	~1	L/s	

North Trib 2

test	length (m)	time (s)	velocity (m/s)
1	2	8	0.25
2	2	9.6	0.21
3	2	9.5	0.21
4	2	9.2	0.22
AVG	2	9.075	0.22
Avg Width	0.85	m	
Avg Depth	0.07	m	
Area	0.03	m^2	
C	0.90		
FLOW	0.01	m^3/s	
	5.9	L/s	

silty bottom
run section
* compared to JFSA Stingray data

North Trib 3

test	length (m)	time (s)	velocity (m/s)
1	3	22.1	0.14
2	3	23.4	0.13
3	3	22.8	0.13
AVG	3	22.76667	0.13
Avg Width	1.15	m	
Avg Depth	0.115	m	
Area	0.07	m^2	
C	1.00		
FLOW	0.01	m^3/s	
	8.7	L/s	

hard stone bottom
run section (small bend)

North Trib 4

test	length (m)	time (s)	velocity (m/s)
1	2.5	8.1	0.31
2	2.5	8.3	0.30
3	2.5	8.6	0.29
AVG	2.5	8.3	0.30
Avg Width	0.8	m	
Avg Depth	0.045	m	
Area	0.02	m^2	
C	1.00		
FLOW	0.01	m^3/s	
	5.4	L/s	

hard clay bottom
run section

Appendix E

Summary of Field Investigations

- **Appendix E1 - Southern Tributary**
- **Appendix E2 - Northern Tributary**

Appendix E1 – Southern Tributary

The following details the results of the Southern Tributary field investigations as described in the photographs and data on **Figure 2**. The Southern Tributary was walked from its eastern extent at Frank Kenny Road to the western edge of the CCV site boundary and key features were documented and presented herein.

Photograph 1 and South Trib 1 Station – Stream flow was measured at station *South Trib 1* to be 5.3 L/s. The temperature of the steam was measured at 12^{o}C (air temperature on June 5, 2013 was 17^{o}C). This measurement represents the amount of water entering the Southern Tributary up gradient of the CCV site. Antidotal evidence has indicated that much of this flow may be derived from sump pumping from the existing Rural Residential neighborhood located to the east. In 2012, this location was shown to be dry during summer field investigations.

Photograph 2 – Moving downstream, a series of springs were observed within the Southern Tributary that were contributing a noticeable amount of flow to the stream. The temperature of the spring water was measured to be ~7^{o}C. The overburden at this location was less than 0.2 m thick and comprised on silt, sand, and limestone rock fragments.

Photograph 3 – More flowing springs were observed along the side of the bank. The temperature of the spring water was measured to be ~7^{o}C. Stream flow was noticeably larger than at *South Trib 1* station.

South Trib 2 Station – Stream flow was measured at this station to be 20.8 L/s. This is a 15.5 L/s increase over the flow measured at *South Trib 1* Station. Stream temperature was measured to be 13^{o}C. Inputs from few small branches as well as 1.4 L/s from northern branch contributed to this increase, but are only able to account for about 3.4 L/s. Minor seepage was observed upstream of the station, but the majority of water is interpreted to be derived from discrete locations of groundwater discharge (springs) likely from the karst bedrock of the Bobcaygeon Formation.

Photograph 4 – Seepage from the interface between the weathered and the unweathered marine clay on the north bank of the tributary was observed. This is seepage is interpreted to be locally derived from the valleyland area around the Southern Tributary where the hydraulic gradient is strong enough to create a groundwater flux towards the creek.

Photograph 5 – Seepage area with iron staining on the south bank of the tributary. Again, this seepage area is interpreted to be derived from local seepage.

Photograph 6 – This photograph was taken just upstream from *South Trib 3* Station. In the area between *South Trib 2* and *South Trib 3* stations, unweathered marine clay dominates the substrate of the Southern Tributary.

South Trib 3 Station – Stream flow was measured at this station to be 27.4 L/s. This is a 6.6 L/s increase over the flow measured at *South Trib 2* Station. Approximately 2.6 L/s of this flow increase is derived from Mid Branch 2. A number of seepage areas and a dry karst spring were observed upstream of this reach and contribute to flow. Stream temperature was measured to be 10°C.

Photograph 7 and South Trib 4 Station – Just downstream from South Trib 3 Station, the watercourse loses its steep gradient (i.e., stream power or energy) and enters into a backwatered, swamp area. This depositional area contains thick stream bed deposits of coarse sand and rounded gravel. The stream flow measured at South Trib 4 Station was 13.8 L/s, which is a decrease of 13.6 L/s or about 50% of flow. Stream temperature was measured to be 12°C. Much of the stream flow is interpreted to be lost to subsurface flow in the thick sediments within this area.

Photograph 8 – Approximately 50 m downstream of South Trib 4 Station, the Southern Tributary loses its defined channel into a swamp area. This is a major barrier to fish passage and may explain why no fish have been observed in the upstream reaches of this tributary.

Photograph 9 – Taken looking eastwards at the outlet of the Southern Tributary to Cardinal Creek. No flow measurements were taken.

Photographs 10 and 11 – Both photographs were taken looking east to north east on the exposed Bobcaygeon Formation bedrock south of the Southern Tributary. Solution enhanced karst pavements were evident on the exposed bedrock and a large number of large fractures could be observed. The major and minor fracture orientations were measured to be approximately 308°W and 18°E or west northwest and north northeast, respectively. The major fracture orientation is directed towards the Southern Tributary, which supports the observation of springs within this feature.

Appendix E2 – Northern Tributary

The following details the results of the Northern Tributary field investigations as described in the photographs and data on **Figure 3**. The Northern Tributary was walked from the La Porte Nursery to near the confluence with Cardinal Creek, and the upper reaches near Ted Kelly Road were visited.

Photograph 12 and North Trib 2 Station – This photograph was taken at the culvert that exits the La Porte Nursery and that contains the JFSA Stingray continuous flow meter. Flow was measured at the *North Trib 2* Station to be 5.9 L/s. The JFSA Stingray flow meter recorded a flow of 5.8 L/s, which confirms the accuracy of the manual stream flow measurements.

Photograph 13 – The Northern Tributary can be seen flowing over the horizontally bedded Gull River Formation bedrock. Groundwater seepage was noted along the banks of the tributary within this area.

North Trib 3 Station – A stream flow measurement was taken at the bottom of the bedrock outcropping to estimate the stream flow increase derived from the bedrock. Stream flow was measured at this station to be 8.7 L/s. This is a 2.8 L/s increase over the flow measured at *North Trib 2* Station. This additional flow is likely derived from the Gull River bedrock and local seepage as baseflow.

Photograph 14 – Similarly to the Southern Tributary, when the Northern Tributary loses its steep gradient, it enters into a backwater, swamp area and loses its defined channel.

Photograph 15 and North Trib 4 – A meandering channel appears following the backwatered area. In this photograph, the tributary is flowing on hard marine clay and has created a large cut-slope near the abandoned railway line. Stream flow measured at the *North Trib 4* Station was 5.4 L/s, which is a decrease of 3.3 L/s from the *North Trib 3* Station. Much of the stream flow is interpreted to be lost to subsurface flow in the backwatered, swamp area. Fish were observed in the tributary, downstream of the backwatered, swamp area.

Photographs 16 and 17 – These photographs show the outcropping of the Gull River Formation north of the La Porte Nursery and south of the abandoned railway crossing. This formation was observed to be finer grained and horizontally bedded, which is consistent with the regional unit description. This area was searched for signs of bedrock outcrops and/or thin overburden to refine the surficial geology based on site specific conditions.

Photograph 18 and North Trib 1 Station – The flow where the Northern Tributary enters the CCV area at Ted Kelly Road was not sufficient to be measured. It was estimated to be ~1 L/s.